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STUDIES ON HOUSEHOLD SEWAGE DISPOSAL
SYSTEMS, PART II

T. W. Bendixen, et al

Environmental Health Center
Cincinnati, Ohio

1950

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STUDIES ON HOUSEHOLD SEWAGE DISPOSAL SYSTEMS

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PART II



Conducted by the
**PUBLIC HEALTH SERVICE IN
COOPERATION WITH THE HOUSING
AND HOME FINANCE AGENCY**

FEDERAL SECURITY AGENCY - Public Health Service - Environmental Health Center

Studies on Household Sewage Disposal Systems

*Second in a series of research reports on
individual sewage disposal systems*

by

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PART II. Septic Tank Compartmentation
Inlets, Outlets, Inter-compartment Appurtenances
Percolation Test Methods
Absorption Systems — Field Survey
Absorption System — Permeability Conditions
Soil Clogging Effects of Septic Tank Effluents

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FEDERAL SECURITY AGENCY

Public Health Service

Environmental Health Center
Cincinnati, Ohio

1950

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1952

Foreword

The significance of the household sewage disposal system in the field of sewage disposal in this country is amply reflected in the 17 million persons estimated as served by residential septic tank — soil absorption systems. With trends toward living in suburban fringe and rural non-farm areas, beyond reach of community sewer systems, the continued utilization of some type of residential sewage disposal is indicated.

Difficulties with the operation of such systems, and attempts on the part of governmental agencies to find and utilize the best available information in this field, have brought out the lack of a basic factual foundation. In order to establish the factual foundation necessary for effective design concepts for the use of governmental agencies as well as others concerned, the Housing and Home Finance Agency and the Public Health Service initiated a broad program of study of this problem, beginning the work in early 1947.

This report, the second of a series, Studies on Household Sewage Disposal Systems, presents the findings on additional individual topics undertaken to date under this program. Additional reports in the series will be prepared from time to time as the work progresses.

In that the final significance of results on some of the individual elements, in relation to the system as a whole, cannot be determined until the facts on related elements, either now under study or to be undertaken later on, are known, caution should be exercised in the application of the piecemeal findings.

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Introduction

SPONSORSHIP

The studies reported herein were initiated November 1948 pursuant to an agreement between the Housing and Home Finance Agency and the Public Health Service, and are a continuation of the program of studies on household sewage disposal systems inaugurated November 1946 under the sponsorship of the (then) National Housing Agency. The studies conducted under the 1948 agreement were jointly financed by H.H.F.A. and P.H.S. equally.

OBJECTIVES UNDER 1948 AGREEMENT

The work projects indicated in the 1948 agreement are as follows:

1. Investigate the effect of compartmentation on the efficiency of laboratory septic tanks as measured by their ability to remove solids.
2. Investigate the relative efficiency of laboratory septic tanks equipped with various inlet and outlet appurtenances such as baffles, tees, dip tubes, bends, wyes, etc.
3. Analyze data collected under the preceding program with reference to soils encountered in absorption fields. Investigate soil clogging characteristics of tank effluents and make studies and recommendations as to the most accurate and most feasible methods for pre-determining the absorption characteristics of soils and field prior to septic tank system installations.
4. Construct equipment of such nature as to permit photographing of the action of materials within septic tanks during operation of the tanks.
5. Make findings of each of the studies outlined above (items 1, 2 and 3) in such form and detail that the information can be adapted for publication as standards or promotional and descriptive technical papers.

The topics mentioned above fall essentially within the broader scope of the eighteen topic objectives outlined in the previous report identified below and not repeated here.

PREVIOUS REPORT

The report, "Studies on Household Sewage Disposal Systems," Part I, 1949, Federal Security Agency, Public Health Service, dealt with seven of the items investigated up to July

1948, which were considered sufficiently advanced in status to be released with proper qualifications. These were:

1. Review of Literature
2. Survey of Controls and Practices in Some Local Health Units
3. Study of Experimentally Operated Septic Tanks
4. Study of Septic Tanks in Field—Sludge and Scum Accumulations
5. Laboratory Investigation of Sludge and Yeast, as Starters
6. Experimental Investigation of the Effect of Zeolite Softener Salts on Digestion
7. Survey of Information on the Freezing Aspects of Household Sewage Disposal Systems

THIS REPORT

This report is the second in the series of reports to be presented as the work progresses. The work covered is essentially that done in the 6-month period from January to July 1949, together with some additional data, pertinent to the topics covered, developed during the previous period of study. As in the case of the previous report, this report is considered in the nature of a progress report.

The topics reported are listed below. Preliminary observations on sewage in a small glass-sided tank were not sufficiently promising to warrant setting up a larger tank for photographic purposes. Further observations will be made. The topics reported herein follow:

- A. Septic Tank Compartmentation Studies
- B. Experimental Studies of Tank Inlets, Outlets and Intercompartment Appurtenances
- C. Field Studies of Possible Modifications of the Percolation Test Method
- D. Examination of Field Survey Data—Absorption Systems
- E. Permeability Conditions in Operating Tile Fields
- F. Soil Clogging Effects of Septic Tank Effluents

PERSONNEL

The Project is operated as one of the activities of the Environmental Health Center at Cincinnati under the administrative direction

of Sanitary Engineer Director V. G. MacKenzie, officer in charge. The staff of the Project during the period mentioned above included the following:

Name	Title	Engineering	Assignment
Weibel, S. R.	Sanitary Engineer		In charge of project.
Sheehy, J. P.	J. A. Sanitary Engineer		Exper. studies, analysis data.
Scientific			
Bendixen, T. W.	Soil Scientist		Soil absorption studies.
Berk, M.	Chemist		Septic tank studies.
Inskeep, J. M.	Scientific Aide		Chemical laboratory.
Gibbons, J. R.	Scientific Aide		Soils laboratory.
Operating			
Ray, H. D.	Skilled Laborer		Experimental plant operation, foreman.
McGuire, N.	Skilled Laborer		Experimental plant operation.
Kennedy, G. C.	Skilled Laborer		Experimental plant operation.
Settles, N. C.	Skilled Laborer		Soil absorption studies.
Clerical			
Fosher, E. C.	Clerk-Stenographer		Central office.

INFORMAL ADVISORY COMMITTEE

Meetings of the Informal Advisory Committee, composed of representatives of the several Federal Agencies, as listed below, were held at the Environmental Health Center in February and April 1949 to discuss progress and advise on various problems in connection with the work, for which grateful acknowledgement is made. The Committee, at the April meeting, advised the setting up of septic tank depth studies as early as possible, in connection with which reconstruction of experimental equipment is in progress. The Committee included the following:

Housing and Home Finance Agency

Office of the Administrator—Mr. L. Shuman.

Federal Housing Administration—Mr. J. R. Simpson.

Joint Committee—Mr. C. A. Betts, Forest Service, United States Department of Agriculture.

Septic Tank Study at University of Michigan (Fed. Research Grant)—Professor E. Boyce.

Public Health Service — Messrs. V. G. MacKenzie, A. H. Stevenson, J. B. Thomas.

CURRENT STUDIES BY OTHERS

From the number of studies going on at the present time by various investigators it is apparent that the importance of this field, and the weakness in its factual foundation, are being given more serious consideration than at any previous time during the past 66 years of household septic tank history in this country. Encouraging also is the entry of manufacturers into experimental and field testing studies on home septic tanks. Some of the studies coming to the attention of the writers during approximately the past year are listed below:

Study	Place	Sponsor
Septic tanks	University of Illinois	Armco Steel Corporation.
Septic tanks	St. Louis, Mo.	Clay Products Association.
Septic tanks	Monrovia, Calif.	M. C. Nottingham Company.
Septic tanks	University of Michigan	Federal Research Grant.
Sewage to soil	Rensselaer Polytechnic Institute	Federal Research Grant.
Garbage in septic tanks	Duval County, Fla.	Duval County Health Department.

Summary

A. Septic Tank Compartmentation Studies

1. A review of the literature on household septic tank compartmentation indicates technical credence, but a hesitancy in recommending it in this country not evident in foreign literature. Little unity of thought with respect to design, shape, size, arrangement and number of compartments is found.

2. In this country the few design recommendations run to rectangular shapes; foreign designs, to both rectangular, and series or segmented cylindrical shapes. Sizes as small as 15 gallons per capita where sewage flows are 5 g. p. c. d. are mentioned; theoretical detention capacities of 2 and 3 days are common, with thoughts running to longer periods in a few instances. Both small and large first compartment recommendations are found, with preponderance of the latter. Recommendations found on number of compartments ranged from two to four.

3. Experimental and survey type studies found were limited to two, an experimental study at the University of Illinois and an examination of survey data on a considerable number of tanks in Victoria, Australia. In both cases compartmentation was found technically advantageous; in both cases a large first compartment was preferred over equal compartments. The Illinois study was confined to rectangular shapes; the Australian study may have included some round shapes.

4. A previous report on this Project, "Studies on Household Sewage Disposal Systems," Part I, 1949, includes the results of experimental operation of 18 septic tanks of single- and multi-compartment design. A year's simultaneous operation of five single-compartment cylindrical, rectangular and oval tanks of approximately 500 gallons capacity, a 553-gallon two-chamber tank, a 673-gallon four-chamber tank and a 2,060-gallon single-chamber tank indicated little difference in average suspended solids removal performance among the five single-chamber vari-shaped tanks of about the same capacity, but considerably higher performance for the two- and four-chamber tanks and for the large single-chamber tank, on

the suspended solids removal basis. The average suspended solids removal efficiencies for the year's run, with sludge added to the tanks at intervals, to simulate accumulations over several years of normal operation, fell between 59 and 65 percent for the five single-chamber tanks of about the same capacity, and were 78, 84, and 82 percent respectively for the three remaining tanks, in the order above mentioned.

5. A study of experimental operation of single-, double-, and triple-chamber tanks, each within the Joint Committee 500-gallon rectangular tank shell, is being made. The average suspended solids removals for the 4-month period, January 17 to May 15, 1949, were 59, 65 and 70 percent for the one-, two-, and three-chamber tanks respectively. The results of the two experimental runs made during this period indicate little difference in average suspended solids removals among the three for the first run, developing into significant differences with the addition of sludge for the second run. Performance appeared to improve with the increase in number of compartments during this run. Operation is being continued. Recently accumulated data indicate variation in performance, and warrant caution against premature conclusions on the basis of the early results mentioned above.

B. Experimental Studies of Tank Inlets, Outlets and Intercompartment Appurtenances

1. A review of available literature on residential septic tank appurtenances indicates the following:

Inlets.—Pipe tees and baffles are common recommendations, with bends, wyes, or combinations being less common. Four States recommend a plain sewer inlet entering above the water line. An external tee and bend permit a plain inlet above mid-depth in a foreign design. Projection of fixtures below water line ranges from 2 to 26 inches in several State recommendations. Projection above water line ranges from 3 to 18 inches. The drop from sewer invert to water line ranges from 0 to 4 inches. The Joint Committee recommends 12-inch projection below and at least 6 inches above the

water line, and a 3-inch drop from the inlet sewer to the water line.

Outlets.—Most States favor the pipe tee or baffle-outlet, with bends, wyes and combinations less common. The foreign external tee-and-bend inlet arrangement mentioned above was also applied to the outlet. Projection of fixtures below water line ranges from 4 to 24 inches for several States and 3 to 12 inches above water line. The Joint Committee recommends 15- to 18-inch projection below and at least 6 inches above the water line.

Intercompartment Flow Appurtenances.—Pipe fittings, single and multiple partition openings, with and without baffles, and weirs, have been suggested in various literature. Partition openings are generally at or above mid-depth. Some "Over and Under" and "Under and Over" arrangements are found; also openings in both top and bottom sections of a partition.

2. Two previous experimental studies of inlets are known, although details are not available. The University of Minnesota experimented with four types of inlets in a small experimental tank equipped with glass windows, reporting a combination bend and transverse tee, and a current-breaker box, to be satisfactory. Pipe-bend and baffle-board designs were reported unsatisfactory. The Michigan Department of Health experimented with inlet, outlet and baffle arrangements, using a dye tracer, and, as a result, eliminated inlet appurtenances from Department recommendations, the sewage entering directly from the sewer about 2½ inches above the water line.

3. Two single-compartment tanks and two three-compartment tanks, each in the Joint Committee 3-foot by 6-foot by 4-foot water depth, 500-gallon shell, were constructed for study of inlets, outlets and intercompartment appurtenances. One tank of each type was equipped with Joint Committee-type tee inlets, outlets, and Ω bend intercompartment fittings, and the other being equipped identically except for the particular variable under study. Exploratory tests of tank detention characteristics under various inlet, outlet and intercompartment arrangements, using uranin dye as a tracer, are being made. These will be followed by suspended solids runs under various sludge accumulations.

4. Experimental dye runs in the pair of 500-gallon single compartment Joint Committee-type tanks, without sludge accumulation, resulted in the following:

(a) The tank equipped with a plain 4-inch sewer inlet, 3 inches above the water line, provided essentially the same experimental detention time as the 4-inch tee-inlet-equipped control tank. The latter, however, had a lower coefficient of dispersion and, therefore, a somewhat better flow pattern for approximately the same experimental detention time.

(b) The addition of an inlet baffle to the plain sewer inlet above mentioned improved the flow pattern as indicated by the lower coefficient of dispersion. The experimental detention times for both the baffled inlet tank and tee inlet control tank were the same.

5. Similar dye runs on a pair of 500-gallon rectangular, three-compartment tanks, without sludge accumulation, resulted in the following:

(a) The tank equipped with a 4-inch horizontal slot extending to tank-width in each partition, submerged 12 inches to top of slot, resulted in an experimental detention time essentially equal to that of an equal size single-compartment tank, but less than half that of the Ω -bend-equipped three-compartment control tank. The coefficient of dispersion of the slotted partition tank was somewhat better than that of the single-chamber tank but not as good as that of the Ω -bend partition-equipped control tank.

(b) A 4-inch-diameter hole substituted for the slot above mentioned in each partition, centered transversely and submerged 12 inches to top of hole, extended the experimental detention time, as compared to the control, over that provided by the slotted tank, in relation to its control in the previous test. A slight improvement in the coefficient of dispersion was also noted.

(c) It appears therefore that for 12-inch submergence, and without sludge accumulation, the detention characteristics of the slotted partition, three-compartment tank were considerably below those of the Ω -bend-equipped three-compartment control tank, while those of the circular-hole-equipped tank approached those of the control tank. Detention behavior under other circumstances of partition slot, hole and

pipe fitting sizes, locations, and sludge accumulations has not yet been investigated.

6. A comparison of the experimental detention characteristics of the pipe-fitting-equipped single- and three-compartment control tanks above-mentioned, which were of essentially equal over-all capacity and shape, indicates improvement in detention characteristics through compartmentation, at the zero sludge accumulation point.

7. A comparison of experimental detention characteristics of pipe-fitting-equipped single-, double- and triple-compartment rectangular tanks, all of essentially equal over-all capacity and shape, indicates progressive improvement of detention characteristics as the number of compartments increased from one to two to three, at the one-sludge accumulation circumstance under which the test was made. Observation of behavior at other sludge accumulation levels is intended.

C. Field Studies of Possible Modifications of the Percolation Test Method

1. Four suggested modifications of the percolation test are made.

(a) Use a 4-inch auger hole in which to make the test, instead of the twelve-inch-square dug hole.

(b) Obtain a reasonable number of replicate tests in any tile field under consideration and use the average rate as the best estimate of soil absorption characteristics.

(c) Fill the test holes with water and allow the soil to soak over night before making the percolation test.

(d) In analyzing the percolation test data consider the later period of the test as being more representative of the true absorption rate of the soil.

2. A limited study to compare methods based on suggested modifications to the method was made on one soil. The results show the importance of making replicate tests, and the importance of analyzing the data more critically. No significant difference between rates obtained with different-sized holes was found.

3. It is expected that the soaking procedure will be more important in soils containing appreciable amounts of clay. The soil used in this study was of a silty texture.

4. The basis of the suggestions made is being further investigated in a continuation of field work on a variety of soils.

D. Examination of Field Survey Data—Absorption Systems

1. Pertinent soils information from the septic tank systems inspected by field crews have been tabulated.

2. A comparison of sewage effluent loading rates applied to these systems, with the percolation test rates in the unaffected soil, tends to agree with the original Ryon study. From this comparison it also appears that for the group of systems examined, the borderline between successful and unsuccessful operation fell at sewage loading rates approximating two percent of the unaffected soil percolation rates.

3. A comparison of percolation rates measured in affected soil areas with percolation rates measured in unaffected soil areas shows a significant correlation in a trend toward reduced rates in the affected soils. However, additional data are needed to develop this relationship for practical use in estimating the magnitude of the reduction in rate.

4. A comparison of percolation rates measured by the unconfined method with rates measured by the confined method also shows a significant correlation. Due to the wide variability in the data, additional data are needed here also before a practical relationship can be established.

E. Permeability Conditions in Operating Tile Fields

Preliminary data on a single operating tile field indicate the following trends:

1. Considerable variation in water absorption properties of a soil may exist within relatively short distances.

2. The size of hole in which percolation tests are made has no effect on the results.

3. The percolation rate distribution across a tile line shows that rates tend to decrease at locations close to the tile line, possibly due to a more complete degree of water saturation in this area, although other factors may be involved.

4. There is evidence that the efficiency of this

particular tile field in disposing of the septic tank effluent must depend a great deal on lateral movement of effluent out of the tile trench.

5. Observation of root distribution in the tile trench of this field showed a concentration of roots in the ground and gravel below the tile line and very few above. No roots were found in the tile itself.

F. Soil Clogging Effects of Septic Tank Effluents

1. Soil clogging experiments were designed primarily to separate soil clogging effects due to physical, biological, and chemical causes. The trends at the present time based on examination of one soil indicate that the clogging during the first several days of dosing of the soil columns is directly proportional to the amount of suspended solids added to the soil. Biological activity in the soil (or on the soil surface) then appears to take effect and reduces the rate of soil clogging. The greater the biological activity the slower is the clogging.

2. Effluent from a septic tank having garbage added seemed to cause more clogging than effluent from a septic tank receiving no garbage. This trend does not hold for the disinfected effluents from the same tanks. Filtered fresh

sewage seemed to clog the soil to an extent intermediate between the normal and the disinfected septic tank effluents. The fresh sewage (which was not disinfected) caused more clogging than the normal effluents but less clogging than the disinfected effluents. All of these trends are based on a limited amount of data on one soil type and should not be regarded as being conclusive.

3. During the 60 days' life of soil cores dosed with normal septic tank effluent, roughly equivalent to 16 months of absorption field operation for the same soil, on the basis of the total suspended solids applied per unit soil area, there was about an 80 percent reduction of the original percolation rate. However, because of slower rate of addition of solids in the field, the possibility of greater biologic activity, and the opportunity for lateral absorption, as compared with the limited circumstances of the core experiment, it is possible that the comparable life of a tile field in the particular soils studied would extend beyond the 16-month period for the same change in percolation rate.

4. Due to the conditions of the soil cores when gypsum was added, no conclusions can be reached at present on the effect of gypsum on percolation characteristics of a soil. Future runs under controlled conditions will be made.

Application of Research Results

"Studies on Household Sewage Disposal Systems, Part II, 1950," the second progress report of a series, deals with the continuance of studies of septic tank compartmentation, the starting studies on tank inlets and intercompartment devices, and starting studies on soil clogging and absorption systems. Most of the work reported is still under way and is consequently incomplete. While attempts have been made to qualify findings for what they are, i. e., results under particular conditions, the piecemeal release of parts of the study, in advance of the entire development, is not without risk, and caution should be exercised in applying the results at this stage.

Conclusions regarding design which the Public Health Service believes warranted, are as follows:

1. Early results in the experimental comparison of compartmented and un compartmented rectangular tanks favor compartmentation. Mixed results developing beyond the period reported herein indicate that longer operation, with additional sludge accumulations, will be necessary to enable adequate appraisal. A tendency for sludge to shift downstream, also developing, indicates need for work on compartment details, such as number and proportion. Operation is continuing.

2. A plain 4-inch sewer inlet, baffled 4-inch sewer inlet and 4-inch tee inlet were found equal in their effect on the experimental detention time of a single-compartment, rectangular tank in short tests at zero sludge accumulation. Flow patterns for the tee and baffled sewer inlets were somewhat better than that of the

plain sewer inlet. Conclusions should be deferred until the longer suspended solids removal tests under sludge accumulation circumstances can be made, and the relation, if any, between detention time and suspended solids removal, investigated.

3. An increase in experimental detention time and improvement in flow pattern resulted from compartmentation of a rectangular tank under particular intercompartment flow device arrangements and at zero sludge accumulation. The design and location of intercompartment flow device appears important in this connection. A three-compartment, rectangular tank with a 4-inch, tank-width slot, submerged 12 inches to top of slot in each partition, provided essentially no improvement in experimental detention time over that of a single-chamber tank of equal over-all size and shape. The substitution of a 4-inch-diameter hole for the slot in each partition, centered transversely, and at the same submergence, increased the experimental detention time. An identical three-compartment control tank, employing vented Ω bends between compartments, provided the longest experimental detention time. Further exploratory tests on appurtenance designs and locations are planned, to be followed by suspended solids removal runs at various sludge accumulations.

4. No significant difference between percolation test rates obtained in different-sized holes was found in limited study thus far. Until further data are developed, the following are suggested:

(a) The use of a 4-inch, or larger, auger hole.

(b) Replication of tests over the absorption area being considered.

(c) Overnight soaking of holes before making the test, particularly in the heavier textured soils.

(d) Use of the percolation rate of the latter part of the test run instead of the early or

average rates. For use with existing tables of absorption area size, rates are expressed as minutes-per-inch.

(e) Tables of recommended absorption-area size derived from the Ryon study, using the 12-inch-square-hole test, may also be used with auger hole tests.

5. For a group of household septic tank soil absorption systems investigated in the field, the borderline between successful and unsuccessful operation fell at sewage loading rates equal to about 2 percent of the unaffected soil percolation rates. Tests were made in the vicinity of, but not close to, the existing tile lines. The range in rates was roughly between 0.5 and 4.0 percent in the variety of soils investigated.

6. In the detailed examination of one absorption system in the field, root concentrations were found in the soil and gravel below the tile, with some above, but none in the tile itself.

7. Considerable variation in water absorption properties of a soil may exist in relatively short distances.

8. Field tests in one absorption system indicated trench bottom clogging. Lateral movement of effluent from the trench and probable evapo-transpiration appeared largely responsible for continued operation.

9. Test columns of one type of soil clogged at a rate proportional to suspended solids added for the first several days of dosing, following which clogging rates reduced, possibly due to onset of biological activity.

10. Effluent from a septic tank receiving ground garbage and sewage appeared to cause more clogging of test columns than effluent from a tank receiving sewage only, in the one type of soil tested, a heavy, reddish-brown clay.

11. Filtered raw sewage (simulating fresh settled sewage) also appeared to cause more clogging than the effluent of a septic tank receiving sewage only, in the one type of soil tested, a heavy, reddish-brown clay.

SECTION A

Septic Tank Compartmentation Studies

INTRODUCTION

A review of the literature on studies of septic tank compartmentation brings to light two published investigations which deal in part with compartmentation, the first an experimental study starting in 1922 at the University of Illinois by Lehmann, Kelleher, and Buswell (1) and the second, a survey of a large number of septic tanks in operation, made by the Victoria, Australia, Health Department, and reported by Hepburn in 1933 (2) and 1936 (3). Both of these indicated some advantage to compartmentation, and are discussed in some detail further on.

There appears to be considerable application of compartmentation in actual practice, although official recommendations in this country on the whole have not promoted compartmented tanks, and, in a few instances, their use is discouraged.

Design Practices

United States. Some half-dozen States include a two-compartment tank in their recommendations. The F. H. A. and the Joint Committee on Rural Sanitation designs also provide for compartmentation. The compartmented tank is usually described as having a first compartment equal to the total capacity of a single-compartment tank, followed by a second compartment of half the capacity of the first, or a total capacity of 150 percent that recommended for a single-compartment tank. In other words, it appears that compartmentation recommendations have carried with them an increase in capacity over the single-chamber tank.

England. Ferguson (4) recommended, for minimum installations, a tank 6- by 2- by 4-foot water depth, with a hanging baffle located two-thirds the tank length from the inlet and 18 inches above the floor.

India. Temple (5, 6) mentioned Clemesha's

experimental work in tank development and described Clemesha's tank as having two compartments, the first one-eighth of tank length, with a hanging scum board in the first chamber. With respect to Chakravarti's minimum size two-compartment, rectangular tank, 6- by 2½- by 2½-feet water depth (for 10 users, deeper for more). Temple's opinion was that such a tank would be upset by a large flush, and he recommended separate storage of bath water for garden use, or for steadying the septic tank flow when not required for garden purposes. Clemesha's experiments indicated a tank capacity of 2 cubic feet per capita (for a strong Indian sewage averaging 5 gallons per capita per day). Chakravarti's tank capacities ranged from 2.21 to 3.75 cubic feet per capita, reducing to 1.5 cubic feet per capita where chlorine was used.

Australia. The Victoria regulations, reported by Hepburn (3) included, among other items, references bearing on compartmentation as follows:

A single-chamber tank, or the first chamber of a multi-chamber tank, is to have its length at least three times its width. Tanks of complicated design will not be accepted, and no allowance will be made for chambers filled or partly filled with stone, coke, etc. Subdivision into a large first and a small second chamber is preferred for all tanks 8 feet or more in length.

New Zealand. The Journal of Agriculture, New Zealand (7) proposes a three-compartment tank, 7- by 2- by 2½-feet water depth.

Rhodesia. Haviland (8) in addition to providing specifications for a single-compartment tank includes the following for a two-compartment tank: length—first, 4¾ feet; second, 2 feet; width—3 feet; water depth—4 feet.

Germany. Schreiber (9) described a tank, usually round, divided into four compartments, to be used either as a "fresh water" tank (short detention type) or as a septic tank. In large

septic tank installations, and those erected of concrete rings, the sludge chamber is a continuation and enlargement of the lower part of the first compartment. Sludge from the second compartment also discharges to the sludge chamber. Compartments 3 and 4 serve for removal of fine material and are completely separated from the sludge chamber. The four-compartment tank was reported to have shown substantially better clarification efficiency than three-compartment tanks of similar size on the basis of experiments with transparent models. In the "fresh water" (short detention type) adaptation, the effluent is discharged from the third compartment, with a sludge removal opening in this compartment leading off to the fourth compartment. It was stated also that scum removal apparatus could be installed in large installations to convey scum directly to the fourth compartment.

Sierp (10) described compartmented tanks using H pipes for passage of wastes from one compartment to another with openings at about mid-depth and arranged diagonally in plan. Sierp claimed that detention periods of 1 to 2 days were too short and suggested 12- to 15-day detention periods, with cleaning at least once a year.

Poland. During a visit to the United States in 1947 Mr. A. B. Szniois* described both rectangular and cylindrical tanks of multi-compartment types in use in Poland. Detention periods for both types are 24 hours minimum, with a preferred period of 72 hours, and installations running as high as 20 days' detention. Capacities for both types are about 264 gallons per capita, with compartment arrangements to provide half the capacity in the first compartment and a quarter each in the second and third compartments of the usual three-compartment tank. Interconnection of compartments is made with cast iron tee fittings.

The width of the compartmented rectangular tank is one-third the sum of the three-compartment lengths. A minimum depth of 4.9 feet is recommended but the preferred depth is 6.6 feet. Inlets and outlets are arranged diagonally opposite each other in each compartment.

The cylindrical tank installation consists of three separate tanks of equal diameter, designed on the same capacity basis as the rec-

tangular tank, with usual depths of 9.8 feet in the first compartment and 4.9 feet each in the last two.

It was deemed advisable to clean the installation when sludge appears in the third compartment. The opinion was advanced that there was no difference in efficiency between the round and rectangular tanks.

EXPERIMENTAL AND SURVEY INVESTIGATIONS

Illinois Study

In a report by Lehmann, Kelleher, and Buswell (1) the results of an experimental study of full-sized septic tanks, operated from 1922 to 1925 at the University of Illinois, are presented. The first part of the study concerned three rectangular tanks of the same cross section, total length, and capacity, with single-, double-, and triple-compartment arrangements. The second part of the study concerned three two-compartment tanks of the same length and capacity but differing in depth and width.

In addition to the two sets of tanks mentioned above, which were operated on Champaign city sewage, duplicates of the two- and three-compartment tanks of the first set, and duplicates of all three of the two-compartment tanks of the second set were set up on individual farm homes for operation under circumstances of the particular home.

The total liquid capacity in each tank in both parts of the study was about 1,080 gallons. All tanks in the first part of the study were 3 feet wide and 12 feet in total length, and had a water depth of 4 feet. The three-compartment tank was formed by partitions at the one-third points; the 2-compartment tank, by a partition located two-thirds of the length of the tank, from the inlet. Tank inlets and outlets were baffled, the baffles set 6 inches from the walls with 8 and 12 inches submergence respectively below the surface. Compartment interconnections consisted of an upstream 4-inch tee with 19 inches submergence, and a downstream baffle 3 inches from the partition, with 8 inches submergence.

The tanks used in the second part of the study were all two-compartment tanks of the

*State Institute of Hygiene, Wroclaw, Poland.

same total length and capacity as those above-mentioned, all with the partition at the two-thirds point. The liquid depths were 3, 4, and 5 feet respectively, with corresponding widths of 4, 3, and 2.4 feet. Other details were the same as those described for the first tanks.

The city-sewage-operated tanks were each dosed daily at 8:00 a.m., 12:00 noon, 5:00 p.m. and 10:00 p.m., the four doses per day totalling one-third of the tank volume, or about 359.5 gallons. Grab samples were taken every sixth day in the first study and every eighth day in the second. Such samples were taken with a special sampler from the tank compartment outlet, either behind the baffle or from within the tee at a point 17 inches below the liquid surface. In the case of the farm tanks the samples were taken during flow or no-flow circumstances as they happened to be at the time. The city-sewage-fed tanks were not sampled while the tanks were being dosed. The determinations made included temperature, turbidity, settleable solids, total solids ash, chlorides, oxygen consumed and ammonia, nitrite, and nitrate nitrogen. No determinations were presented on raw sewage characteristics.

Considering the one-, two-, and three-compartment tanks of the same depth, width, total length and capacity, all operated at a theoretical detention of 72 hours, it was concluded that the two-compartment tank gave best results. A comparison of results from the single-compartment tank (72-hour theoretical detention) and the first compartments of the two- and three-chambered tanks (48 and 24 hour theoretical detention respectively) was also made. From this it was judged that, although there were points in favor of the first compartment of the two-chambered tank over that of the three-chambered tank and also over the single-compartment tank, a 50 percent additional capacity for sludge storage should be provided. In designing a single-chamber tank, or the first chamber of a multi-compartment tank, the space allowance should be designed for a 48-hour detention plus 50 percent additional for sludge storage, or a total detention of 72 hours. A further comparison between the first chamber of the two-compartment tank and the first two chambers of the three-compartment tank (48-hour theoretical detention period in both cases) was made, from which it was concluded that the

single chamber gave better performance than the two chambers at the 48-hour theoretical detention period. This was attributed largely to accumulations of sludge and scum in the first compartment and reduction of effective capacity and retention period. Summing up, it was concluded that for tanks with a 72-hour total capacity there was advantage to two chambers, but for a 48-hour total capacity, no advantage in two compartments; further, that a two-compartment tank is desirable if the first chamber provides 48 or more hours' detention. Increased settleable solids in effluents after several months' operation was thought probably due to sludge and scum accumulations; the variation in effluent solids to intermittent gasification.

As to the second phase of the study, in three two-compartment tanks of the same capacity, length, and cross-sectional area, but with 3-, 4-, and 5-foot depths and corresponding widths of 4, 3, and 2.4 feet respectively, the statement was made that no definite relationship between shape of cross section of a septic tank and the efficiency of its operation was discovered.

For both the city-sewage-dosed two-compartment tanks (72 hours theoretical detention) and the same type and size of tanks on three farms, (theoretical detention periods of 273, 118, and 148 hours respectively) it was stated that the final effluent was of better quality than that of the first compartment.

The sludge and scum accumulations from the three farm-home installations during 32½ months of operation were equivalent to an average of 3.35 cubic feet per person per year.

The design recommendations drafted as a result of the studies were briefly as follows (insofar as the smallest installations are concerned; larger ones are also listed):

- (1) Average sewage flow allowance for farm homes of 7 people—25 gal./cap./day. (Smaller unit quantities are given for larger homes).

- (2) For single-chamber tank, 48 hours' effective retention plus 50 percent additional for sludge, or a total of 72 hours.

- (3) For a more efficient plant, a 108-hour two-chamber tank having a 72-hour first chamber and an additional 36 hours in the second.

- (4) Make minimum tank large enough for 7 persons.

- (5) Use tank cross-section 3 feet wide with

4-foot depth of sewage. (For minimum tank a table lists a first compartment, or a single-compartment tank, 6 feet long, and a second compartment 3 feet long).

(6) Sketches of suggested single- and two-compartment tank designs are given. For the minimum tank (7 persons or less) the chamber and depth dimensions above indicated are given. The inlet pipe enters the tank 4 inches higher than the outlet pipe in both the single- and two-chamber tanks. An inlet baffle 10 inches from the wall penetrates about 12 inches into the sewage in both cases; the outlet baffle, 3½ inches from the wall penetrates about 15 inches. A concrete partition wall at the two-thirds point is equipped with a 4-inch by 2½-foot horizontal slot (not investigated experimentally) the top of which is located about 18 inches below the sewage surface. A freeboard of about 12 inches is indicated by the sketches for both types of tank.

Victoria, Australia, Study

Hepburn (3) reported in 1936 an examination of field inspection data on a large number of septic tanks. An accumulation of data on 300 systems which had been examined about 1933 for the purpose of setting up empirical design standards for the State of Victoria, had been increased to 1,088 tanks at the time of the second analysis reported here. After elimination of tanks serving hotels, schools, factories, and other premises differing from dwelling conditions, as well as new or recently-cleaned tanks and those treating mixed sewage or for which insufficient data were available, a total of 726 tanks remained for this examination. The group was limited to tanks serving residential buildings as dwellings, boarding houses, benevolent institutions, etc., treating sewage from closets and urinals only, and ranging in size from 35 (42 U. S.) to 8,700 (10,400 U. S.) gallons.

"In deciding whether a tank should be classed as satisfactory or not, an arbitrary standard was adopted, based on the fact that a person installing a septic tank system wishes, inter alia, to avoid the expense and inconvenience involved in frequent removal of solid matter from the tank, the standard being that—

"(a) The tank should be capable of operating for at least three years before removal of sludge and scum becomes necessary.

"(b) It should not, within that period, discharge suspended matter in such quantity as to interfere with the operation of a filter, or to choke the pores of the soil around subsoil-absorption drains.

"(c) It should not give rise to offensive odors."

In making the examination of the data the field was broken down into class intervals on the particular variable being investigated and the percentage of satisfactory tanks in each class interval, on the basis of the above-mentioned criteria, determined.

In appraising the results which follow it should be borne in mind that the daily sewage flow from closets and urinals only, which is the usual load, was reported as seldom exceeding 10 (12 U. S.) gallons per capita, and more likely to be in the region of 6 (7 U. S.) gallons per capita.

Concerning tank capacity it was indicated that a high proportion of satisfactory tanks was not reached until the capacity exceeded 100 (120 U. S.) gallons per capita. Of the tanks falling in the less than 100 (120 U. S.) gallons per capita group only 10 percent were classed as satisfactory. From a graph of the data, not reproduced in the report, it was concluded that the minimum capacity for a satisfactory septic tank could be obtained from a straight line having the equation: "capacity = $C + 10N$," C having a value of 250 to 300 (300 to 360 U. S. gallons) N being the number of persons served.

Examination of water depths was made after eliminating all tanks which were unsatisfactory from a capacity standpoint (those for which basal capacity C was less than 200 (240 U. S.) gallons.) The examination indicated a high proportion of satisfactory tanks in the depth intervals 3 feet 1 inch to 4 feet and deeper. It was thought reasonable to conclude that if tanks of bad shape and with bad details in inlet pipes, baffles, etc., were eliminated, most if not all, unsatisfactory tanks over 3 feet deep would drop from the table. The mean depth of the 3 feet 1 inch to 4 feet class was therefore taken as the minimum satisfactory depth (3 feet 6 inches.)

An examination on shape characteristics in tanks in which basal C exceeded 200 (240 U. S.) gallons and depth exceeded 3 feet was consid-

ered inconclusive, with the percentage of satisfactory tanks showing no relation to the proportion of length to width. It was considered that the only useful figure on this derived from a group of 81 tanks in one municipality for which an appraisal was made in the earlier study. All of these tanks were of reasonable depth and capacity and were two compartment tanks, with a large first and a small second chamber, but with wide variation in the ratio of length to width of the first chamber (1:1 to 4:1). The ratios of length to width were worked out for the first chamber with the expectation that these would more correctly apply to a single-chamber tank than figures obtained by considering the whole tank. An increase in the percentage of satisfactory cases developed with increase in ratio of length to width. The conclusion was drawn that the best plan proportion for the first chamber of a multi-compartment tank, or for a single-compartment tank, would be a length-width ratio of at least 4 to 1, but that if both capacity and depth were adequate, a 3 to 1 ratio would probably give satisfaction.

As to compartmentation, 322 tanks exceeding the basal C = 200 (240 U. S.) gallons and with depths greater than 3 feet were examined under four groupings:

- (a) Single-compartment tanks.
- (b) Tanks with two approximately equal compartments.
- (c) Tanks having a large first compartment and one or more small secondary compartments.
- (d) Tanks with multiple "under and over" baffles.

The only conclusion felt justified from examination of the tabular distribution was that the "under and over" baffled tanks were less efficient than the other forms (percentage "Satisfactories" were 85, 89, 87 and 70 respectively for the groups listed above, and 86 for the whole). From observations on sludge and scum data, not presented in the report, the examination was extended. From this it was concluded that the two equi-compartment tanks were uneconomical, as the second chamber seldom collected more than 6 inches of sludge, and no scum, until the first chamber was approaching a point at which complete blockage might occur. It was thought that if the tanks of this type in which the first compartment had become nearly full of sludge and scum in less than 3 years

were classed as unsatisfactory, this type of tank would show up as less efficient than either single-compartment tanks or multi-compartment tanks having large first chambers.

As between single-compartment tanks and multi-compartment tanks having a large first chamber, it was reported from observation of effluents (not based on analytical data) that the single-compartment-tank effluents were always visible turbid except where capacity was very large, while those of the multi-compartment tanks usually contained only minute suspended particles. Taking into account cost, ease of desludging and quality of effluent it was felt that a former recommendation could be repeated:

(1) A tank more than 8 feet long should consist of two chambers, the first having two to four times the capacity of the second.

(2) A tank 6 feet or less in length should be in the form of a single chamber, owing to the difficulty of desludging a second chamber less than 2 feet long.

(3) A tank between 6 and 8 feet long may consist of either one or two chambers at the discretion of the designer.

An examination of data for about half the total number of tanks revealed no relationship between surface area per capita and satisfactory operation of the tank. It was observed that scum formation is very variable, ranging from a few inches up to 18 or 24 inches thick in similar tanks, in operation for the same time and under apparently similar circumstances.

Many of the tanks inspected had a compartment, usually the last, filled with broken stone, coke, charcoal, etc., with sewage entering either at the bottom or top, in connection with which it was found quite generally that the filling material was hidden under a layer of sludge. In a few tanks in which the middle cell of a three-compartment tank was so used, with sewage entering this compartment through low level slots and leaving over a weir, it was found that the third chamber contained a large amount of sludge. From these observations it was concluded that the space taken up by such materials is wasted and could be used to advantage as additional sedimentation and sludge storage space.

As to tank details, the most effective form of inlet for a small septic tank was considered to

be a tee with its lower end not more than 18 inches below the waterline, and open above. It was concluded from this study also that a small first compartment, or an inlet pipe or weir followed by a deep baffle, is undesirable, as paper and fecal matter tend either to rise and form a heavy offensive scum over the whole surface, or to form a pad against the baffle, gradually enlarging until the inlet is blocked. It was thought that a hopper-bottomed tank would lessen cleaning costs by enabling sludge to be pumped out without removing the overlying liquid. Slopes of 1 in 3 were reported adequate, or even 1 in 5 or 6 where bottoms slope toward the inlet end, and although removal is incomplete in these cases, this was considered advantageous in maintaining alkaline conditions.

The number of tanks receiving mixed household sewage was considered insufficient to warrant general deductions, but it was felt that a tank capacity determined from the formula $\text{Cap.} = 400 + 30N$ ($\text{Cap.} = 480 + 36N$ in U. S. gallons) would not be excessive.

The Victoria departmental recommendations made as a result of this study are quoted below:

"Departmental Rules

"Based on the above investigations, the rules which departmental officers will work in future when examining and making recommendations concerning plans of septic tanks will be:

"1. Capacity— $300 + 30N$ gallons or more.

"2. Depth not less than 3 feet 6 inches for tanks up to 600 gallons capacity, and proportionately more for larger tanks. Where the presence of ground water or hard rock makes attainment of such depth difficult, some reduction may be permitted if the capacity is increased.

"3. A single-chamber or the first chamber of a multi-chamber tank to have its length at least three times its width. A lower ratio may be accepted for a tank in an awkward situation, provided that the capacity is increased.

"4. Tanks of complicated design will not be accepted, and no allowance will be made for chambers filled or partly filled with stone, coke, etc. Subdivision into a large first and a small second chamber is preferred for all tanks 8 feet or more in length but will not be enforced."

Previously Reported Compartmentation Studies (1949 Report)

Among a number of studies undertaken during the first year and a half of the H. H. F. A.-

P. H. S. Household Sewage Disposal Study was the experimental operation of 18 full-sized septic tanks of a variety of shapes and circumstances of compartmentation.

The exploratory study brought out a number of experimental findings on the behavior of household-size septic tanks in the removal of suspended solids. Among them were a much higher general level of efficiency than was expected of such tanks; indications that single-compartment tanks of about 500 gallons capacity and varying somewhat from the generally recommended rectangular shape gave about the same performance as the rectangular shape; indications of superiority of a multi-compartment arrangement over the single-compartment, not only in solids removal efficiency, but in permitting greater sludge storage for the same capacity; and indications that small-capacity tanks provide but a short high-level operating period and require frequent cleaning.

The results of the experimental work above-mentioned are presented in detail in the previous report, "Studies on Household Sewage Disposal Systems," Part I, 1949, Federal Security Agency, Public Health Service.

The suspension of experimental and field work at the end of June 1948, due to budgetary circumstances, forced an untimely halt on a number of experiments which were under way, among them an initial run on a set of compartmented tanks in the rectangular shape. The latter was started anew with the resumption of some of the work on the project in January 1949, and the status of the continued work on the rectangular multi-compartment tanks from January 17 to May 15, 1949 is presented further on.

A brief account of the previous exploratory work on compartmentation is presented here in order to give a clearer picture of the entire study of compartmentation on this project to date.

An initial group of eight septic tanks, six of which were single-compartment tanks and the remaining two, two- and four-compartment tanks composed of vertical cylinders in series, were placed in operation June 9, 1947. One large single-compartment tank in the group had a capacity of 2,060 gallons. The remaining 7 tanks ranged from 455 to 673 gallons in capacity, the singles being 513, 525, 455, 539, and

492 gallons, and the two- and four-compartment tanks 553 and 673 gallons respectively.

Subsequent additions to the group included a 539-gallon single, August 19, 1947; a 123-gallon single and a 246-gallon double, December 4, 1947; a 289-gallon triple, January 5, 1948; and 405-gallon single and 539-gallon single, 524-

gallon double, and 509-gallon triple, May 3, 1948. The layout and description of these tanks are presented in plate 1 and table 1 respectively. Previous single-compartment tanks 9 and 7 are currently operating as single- and double-compartment tanks 9A and 7A, respectively.

TABLE 1.—Description of septic tanks

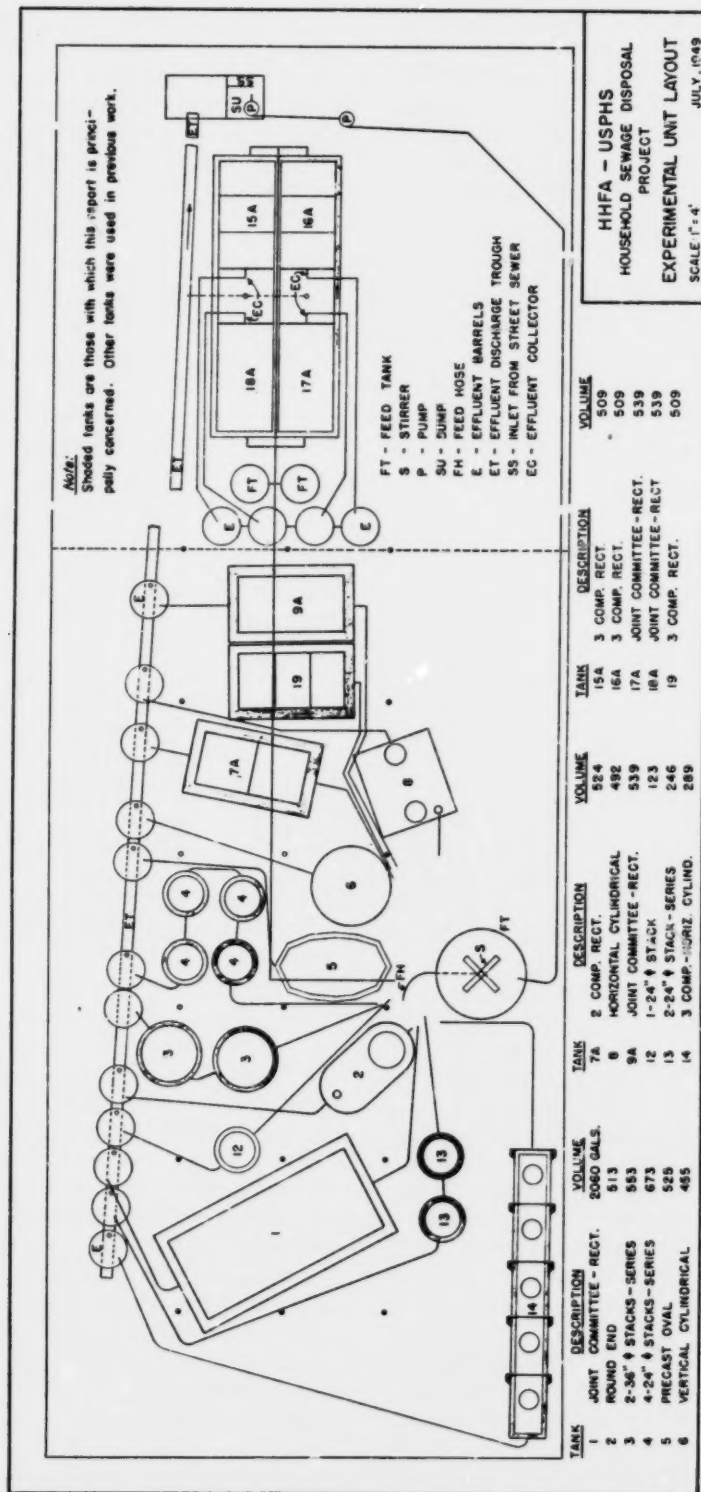
Tank No.	Start Date	Total Liq. Cap.	Description				Remarks
			Width	Length	Dia.	Liq. Depth	
1.....	6/9/47	2,060	5'0"	11'0"		5'0"	Rect. jt. comm. type
2.....	6/9/47	513	2'11"	5'10"		4'5"	Round ends
3.....	6/9/47	553			2@3'0"	5'3"	2-comp. vert. cyl.
4.....	6/9/47	673			4@2'0"	7'3"	4-comp. vert. cyl.
5.....	6/9/47	525	max. 3'4"	6'0"		4'3"	Oval-operated as tank 5A 1/17/49
5A.....	1/17/49	525	max. 3'4"	6'0"		4'3"	Oval-contents of garbage receiving tank No. 9 tran. to 5A 1/17/49
6.....	6/9/47	455			4'4"	4'0"	Sing. vert. cyl.
7.....	6/9/47	539	3'0"	6'0"		4'0"	Rect. jt. comm. type changed to 7A—1/17/49
7A.....	1/17/49	524	3'0"	3'+3'		4'0"	2-comp. rect.
8.....	6/9/47	492		5'0"	4'4"	3'9"	Hor. cyl.
9.....	8/19/47	539	3'0"	6'0"		4'0"	Rect. jt. comm. type, receiving ground garbage with sewage—Contents emptied 1/17/49, reidentified as Tank 9A
9A.....	1/17/49	539	3'0"	6'0"		4'0"	Rect. jt. comm. type dosed with sewage
10.....	8/20/47	539	3'0"	6'0"		4'0"	Rect. jt. comm. type
11.....	8/20/47	539	3'0"	6'0"		4'0"	Weir outlet
12.....	12/4/47	123			2'0"	5'3"	Sing. vert. cyl.
13.....	12/4/47	246			2@2'0"	5'3"	2-comp. vert. cyl.
14.....	1/5/48	289			2'0"	1'6"	3-comp. hor. cyl.
15.....	5/3/48	539	3'0"	6'+6'+3'		4'0"	Rect. jt. comm. type
15A.....	5/20/49	509	3'0"	2'+2'+2'		4'0"	3-comp. rect.
16.....	5/3/48	524	3'0"	3'+3'		4'0"	2-comp. rect.
16A.....	5/20/49	509	3'0"	2'+2'+2'		4'0"	3-comp. rect.
17.....	5/3/48	509	3'0"	2'+2'+2'		4'0"	3-comp. rect.
17A.....	5/20/49	539	3'0"	6'0"		4'0"	Rect. jt. comm. type
18.....	5/3/48	405	3'0"	6'0"		3'0"	Rectangular
18A.....	5/20/49	539	3'0"	6'0"		4'0"	Rect. jt. comm. type
19.....	1/17/49	509	3'0"	2'+2'+2'		4'0"	3-comp. rect.

Except for a short experiment on outlet behavior in two of the tank shells of the last group, prior to group operation on the date above indicated, all tanks were operated until suspension of the Project June 28, 1948, providing slightly more than a year's operation for the original group of eight tanks and shorter periods for the later installations, amounting to a minimum of less than two months for the last group installed.

All tanks were dosed eight times daily on the same pattern and with the same amount of sewage, each receiving an equal portion of each of eight batches of sewage placed in the central dosing tank daily. The eight doses making up

the total daily load were not equal but were proportioned on the basis of a domestic water use curve developed from water meter recordings on several homes. Each intermittent dose was applied at a rate of 10 gallons per minute. The tanks were fed in rotation during each of the 8 doses applied daily from a 650-gallon dosing tank equipped with hook gage and stirrer. The starting point for each round of doses was advanced one tank over the last, to minimize the effects of stratification in the dosing tank. Each tank was equipped with an effluent receiver to enable the collection of representative samples for compositing.

Each tank was seeded with sludge obtained



from septic tank cleaners before being operated. A volume equal to 10 percent of the septic tank capacity was added for this purpose.

The raw sewage was obtained from a city combined sewer serving a small residential hillside area near the laboratory. The sewage was fresh and the solids disintegrated. Dilution during local showers was of short duration due to rapid runoff. A grit pocket preceded the raw sewage pump. Intermittent discharge of acid from the single factory in the tributary area proved troublesome during the first four months of operation, causing delay or omission of individual doses at times until such discharges were discontinued through action of the city authorities.

Samples of raw sewage in the dosing tank, and of the effluent in the receiver of each septic tank were collected at each of the eight daily doses and composited on the basis of the volume of sewage applied. It was found that daily

composites did not differ significantly from the average of separate determinations on each fraction, and further that samples could be composited for as long as a week without significant change so long as the samples were kept refrigerated (40° F.). The analytical routine adopted was to make the determinations twice weekly on 3- and 4-day composites.

The experimental operation of the septic tanks was started on the basis of a 500-gallon per day loading on each tank. After a run of about 2¼ months the daily loading was reduced to 250 gallons per tank, which was maintained throughout all subsequent runs. The dates and circumstances of the six runs, to June 28, 1948, identified as Series 1, 2, etc., are given in the table following, together with the run identified as Series 7 and 8 representing the resumption of operation during the period January 17 to May 15, 1949 for some of the previous tanks:

TABLE 2.—Operating schedule

Series	Duration	Tanks Operated*	Sewage Load-g.p.d.	Sludge Additions
1.....	6/9-8/18/47.....	1 thru 8.....	500	Seed, 10% of tank cap.
2.....	8/20-9/23/47.....	1 thru 11.....	250	Seed 9 thru 11, 10% of tank cap.
3.....	10/11-11/8/47.....	1 thru 11.....	250	200 gal. to 1 thru 9
4.....	11/24/47-2/15/48..	1 thru 9, 12 thru 14..	250	Seed 12 thru 14, 10%; 200 gal. to 1 thru 9
5.....	2/23-3/28/48.....	1 thru 9, 12 thru 14..	250	710 gal. to No. 1; 37.5 gal. to 12 thru 14
6.....	3/30-6/28/48.....	1 thru 9, 12 thru 18..	250	62.5 gal. to 1 thru 9 and 12 thru 18
7 & 8.....	1/17/49-5/15/49..	2 thru 6, 8, 12, 9A, 7A, 19.	250	Nos. 2, 6, 8, 12 emptied and started anew; seed to 2, 6, 8, 9A, 7A and 19, 10%. No. 5 emptied to receive entire contents No. 9 (garbage-sewage) for further oper.

*Either started during particular series or operated over the whole period.

Tank performance

Considering absorption in the soil as the ultimate disposal of home septic tank effluent and realizing the importance of suspended solids in this connection, the suspended solids characteristic of the sewage was chosen as the immediate basis for comparison of performance. It is recognized that other factors of import may develop from a study of the soil clogging mechanism. A start has been made on this as reported further on.

As may be seen in detail in the previous report, the first series operation of tanks Nos. 1 through 8, identified in tables 1 and 2, and shown in plate 1 and in appendix A, plates 24 through 28, (present tank No. 7A previously

operated as single-compartment tank No. 7), brought out a rather broad spread of average percentage suspended solids removal efficiencies for the group. These ranged from 15 to 34 percent for the five single-compartment tanks in the 500-gallon range (tanks 2, 5, 6, 7 and 8), 59 and 56 percent respectively for the two- and four-compartment tanks (tanks 3 and 4), and 60 percent for the 2,000-gallon single-compartment tank. The loading during this 10-week run was 500 gallons per day. The tanks were seeded with sludge obtained from cleaners; 10 percent of tank volume was applied.

The second series run which followed was characterized in operation by a reduction of the load to 250 gallons per day, a volume more rep-

representative of field loading circumstances. No additional sludge was added. The average percentage removals during the second series ranged from 53 to 65 for the 5 single tanks, 58 and 76 respectively for the double and quadruple tanks, and 76 for the large single tank.

It is notable from these two runs that the decrease in loading not only raised the general level of efficiencies but considerably narrowed the spread of average efficiencies among the 5 varishaped single-compartment tanks (range first series, 15 to 34 percent; second, 53 to 65 percent.) There was essentially no change in the performance of the two-compartment tank. The four-compartment tank efficiency improved from 56 percent for the first run to 76 for the second. The large tank also improved, from 60 percent for the first series to 76 for the second.

The third and fourth series were characterized by the addition of a septic tank sludge-sewage mixture, obtained from cleaners, to each tank before starting each of these runs, the amounts added being 200 and 300 gallons respectively. The effect during the third run was somewhat varied for the 5 single-chamber tanks in the 500-gallon class, one tank decreasing in efficiency while the others either held or improved their previous efficiency. The spread of efficiencies for these tanks was 50 to 67 percent. The multi-chamber tanks advanced to 84 and 89 percent respectively while the large single tank reached 84 percent. During the fourth run all five of the single 500-gallon class tanks averaged in the 70's, the range being 72 to 76 percent. The multi-compartment tanks held their third run efficiency levels with 83 and 88 percent respectively, as did the large single tank with 81 percent.

Shortly after the fourth run on tanks 1 through 8 was started, the following three additional tanks were put into operation: No. 12, single vert. cyl., 123 gallons; No. 13, two vert. cyls. in series, total 246 gallons; and No. 14, triple-compartment (hor. cyl.), total 289 gallons. The additional tanks which were operated at the same 250-gallon daily loading schedule as the older tanks, and were seeded with sludge equal in volume to 10 percent of tank capacity, averaged suspended solids removal of 58, 77 and 71 percent respectively for the run.

The fifth and sixth runs produced a mixed falling off of performance in the 5 single 500-gallon-class tanks, and some variation in the multi-chamber tanks and in the large single tank as well. The 500-gallon-class single tanks ranged from 40 to 60 percent for the fifth run and from 20 to 64 percent for the sixth. The two-compartment tank averaged 80 and 66 percent for the two runs respectively; the four, 89 and 88 percent; and the large tank, 59 and 82 percent respectively for the two runs. The smaller tanks performed as follows for the fifth and sixth series: No. 12, 51 and 10 percent; No. 13, 71 and 28 percent; and No. 14, 78 and 4 percent respectively.

The average percentage suspended solids removals above-mentioned may be compared in table 3. These are based on the raw sewage solids added. In table 4 may be found the overall suspended solids removal efficiencies from the initial operation of each tank through the particular series, based on all suspended solids added to the tank, i. e., sewage plus seed plus subsequent sludge additions.

It will be noted from inspection of tables 3 and 4 that the eight tanks which were operated

TABLE 3.—Average suspended solids removals (percent) each series (based on raw sewage solids)*

Series	Tank number										
	1	3	4	2	5	6	7	8	12	13	14
1.....	60	59	56	26	15	18	16	34	-----	-----	-----
2.....	76	58	76	60	61	53	65	59	-----	-----	-----
3.....	84	34	89	50	59	61	66	67	-----	-----	-----
4.....	81	83	88	72	75	73	75	76	58	77	71
5.....	59	80	89	48	61	57	64	40	51	71	78
6.....	82	66	88	35	44	28	64	-20	10	28	4

*Pounds raw sewage S. S.—pounds effluent S. S.

Pounds raw sewage S. S. $\times 100$ = percent removal.

TABLE 4.—Average suspended solids removals (percent) from start through particular series (based on sewage+sludge solids added)**

(Through) series	Tank number										
	1	3	4	2	5	6	7	8	12	18	14
1.....	64	60	57	28	17	20	19	36	-----	-----	-----
2.....	66	60	60	33	24	25	26	40	-----	-----	-----
3.....	78	75	76	55	48	52	53	61	-----	-----	-----
4.....	81	79	81	64	61	63	64	69	60	78	73
5.....	81	79	82	62	61	62	64	67	60	78	77
6.....	82	78	84	61	60	59	65	61	44	63	49

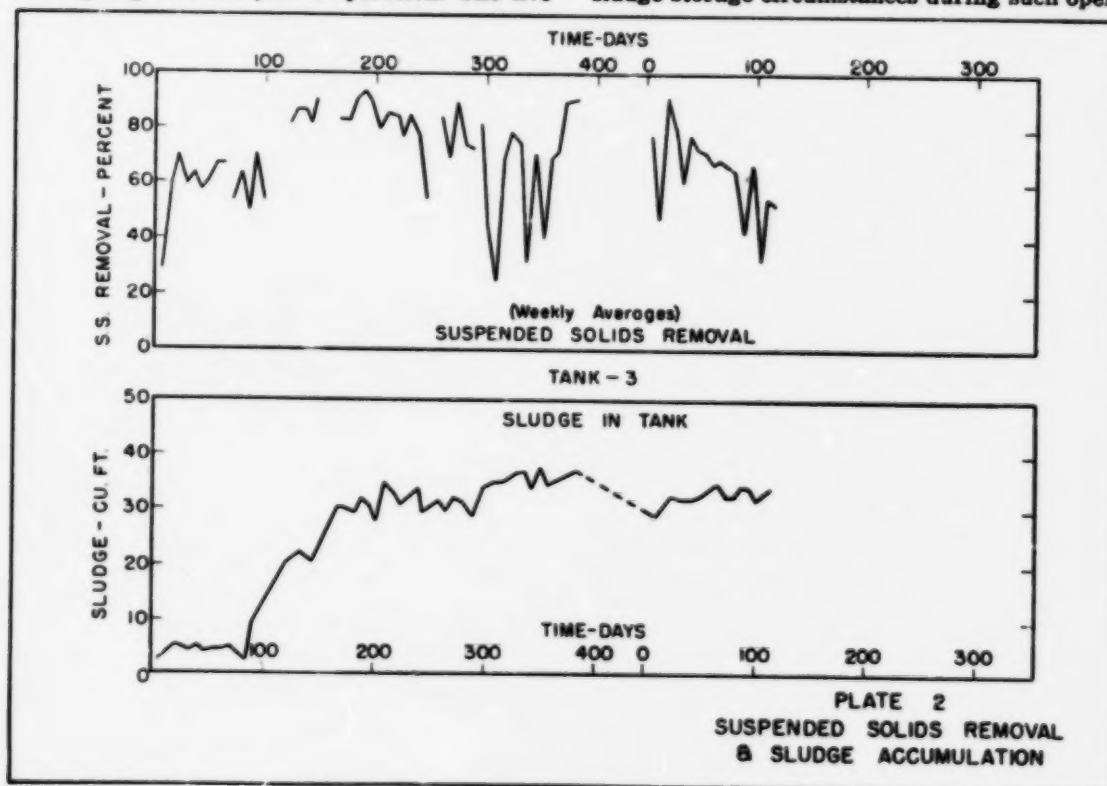
**Pounds raw sewage and added sludge S. S.—pounds effluent S. S.

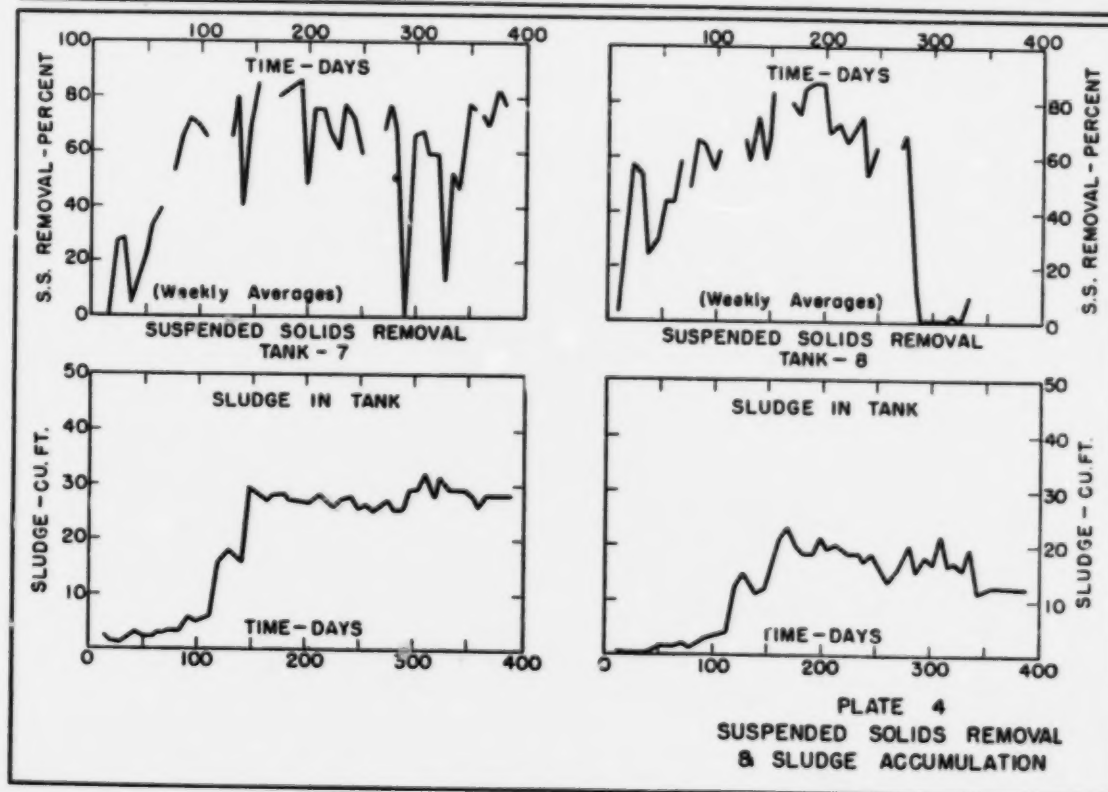
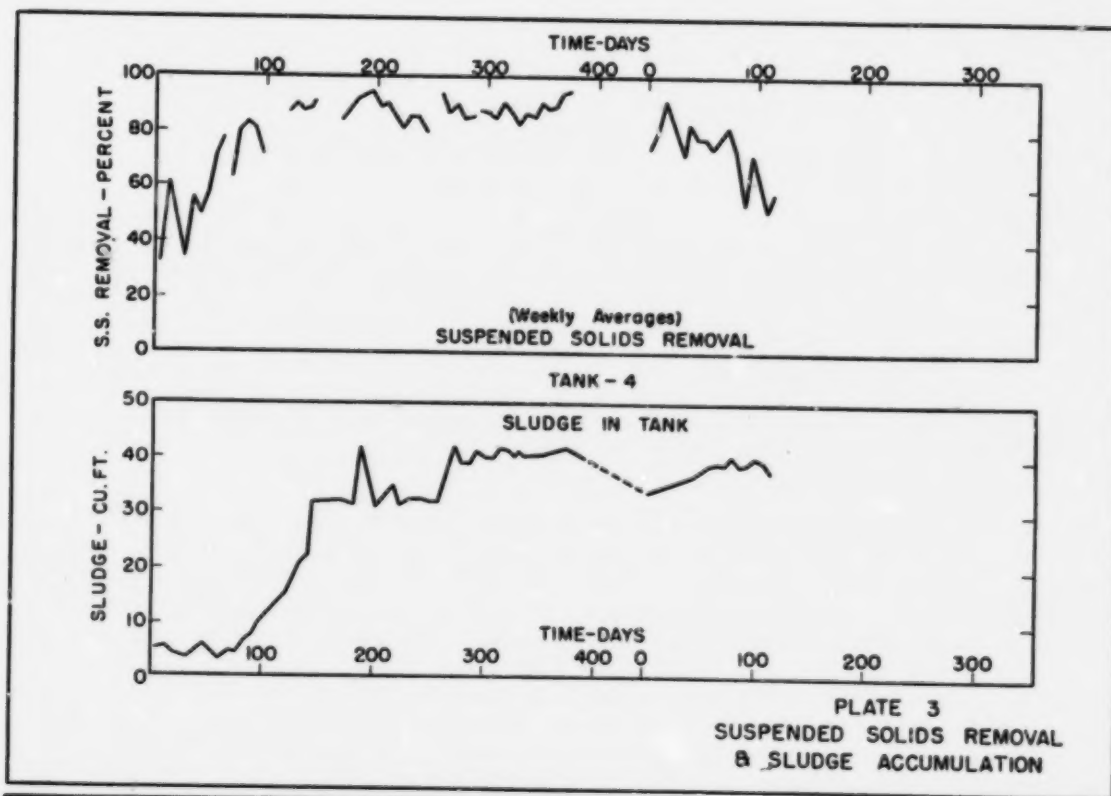
Pounds raw sewage and added sludge S. S.

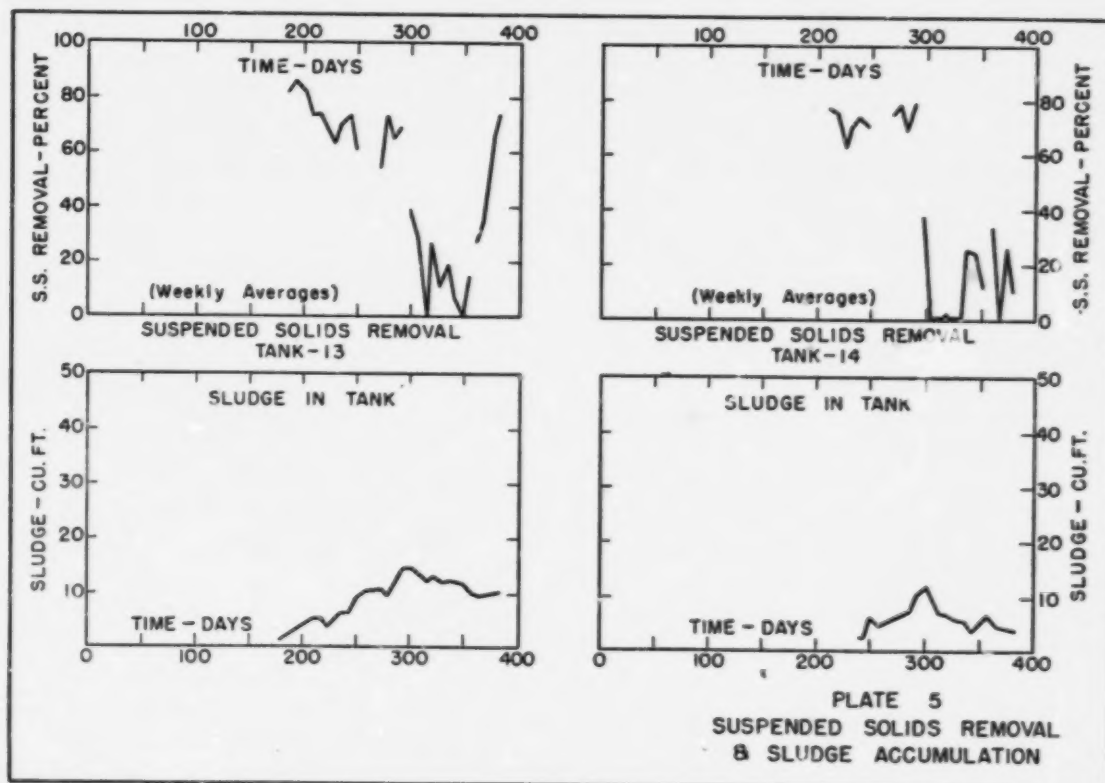
×100 = percent removal.

for a year separated themselves into two groups from the start on suspended solids removal efficiencies, the five single-compartment, 500-gallon-class tanks as one group, and the two multi-chamber tanks and the large single tank as the other group, operating at a higher level. The over-all efficiencies, based on sewage plus sludge added, shown in table 4 for the sixth series, indicates the narrowness of the range in each group for the year's operation. The five

single 500-gallon-class tanks are bracketed between 59 and 65 percent, and the two multi-chamber and the large single-chamber tanks, between 78 and 84 percent. The three smaller tanks, which started out with creditable performances during the fourth and fifth runs, dropped during run six. Not only was their higher performance of comparatively short duration in the experimental operation, but the sludge storage circumstances during such oper-







ation indicated short life between cleanings.

On plates 2 to 5 inclusive are plotted the weekly average suspended solids removal efficiencies, together with sludge accumulations for tanks Nos. 3, 4, 7, 8, 13, and 14. The operation of tanks Nos. 3 and 4 were continued upon resumption of the Project January 17, 1949, and the plot of their performance to May 15, 1949, is also presented. Their average removals for this period were 63 and 72 percent respectively. From the dropping efficiency and variability in the weekly results it appears that peak sludge storage may have been reached. Their operation is being continued. The plots of performance and sludge circumstances for tanks 7, 8, 13, and 14 are also reproduced for comparison of the single-compartment tanks with the multi-chamber type.

Because of the short run afforded the three tanks set up shortly before the Project suspended operation in June 1948, to investigate compartmentation in the rectangular-shaped tanks, the continued study of compartmentation in rectangular tanks was included in the new

agreement. In resuming the study, tanks other than those in which the work was begun were used because of previous leakage troubles. The tanks now being used are designated 9A, 7A, and 19. All are 3 feet wide by 6 feet long by 4-foot water depth. A 2-inch transverse partition installed at the mid-point divides tank 7A into two equal compartments; two such partitions at the third points divides tank 19 into three equal compartments; tank 9A, operating as a single-compartment tank, serves as a control. All are identified in table 1, plate 1, and in appendix A, plate 29. Tank 19 was newly constructed for the study while tanks 9A and 7A were the No. 9 and revamped No. 7, respectively, of the previous work.

CONTINUED STUDY OF COMPARTMENTATION

Methods

Seeding. Before starting operation, tanks 9A, 7A, and 19 were seeded with well-digested

sludge to 10 percent of tank volume. This seed sludge was in storage from the previous series and the solids characteristics are outlined in table 5.

TABLE 5—Solids characteristics of seed sludge

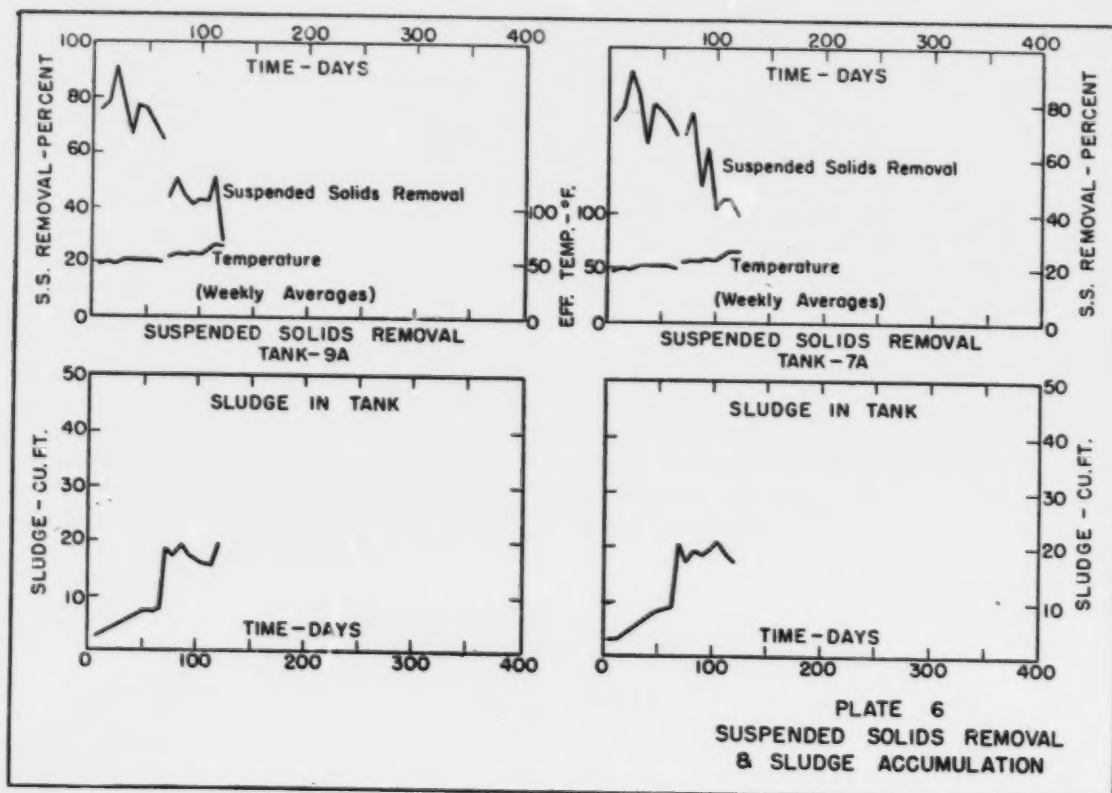
Total solids	25,170 p.p.m.
Ash	15,167 p.p.m.
Volatile matter	10,003 p.p.m.
Percent volatile	39.8 percent

Seed sludge was added in such a manner that it was evenly apportioned between the compartments of tanks 7A and 19.

Operation. Operations were carried on in the manner followed in the previous work. The total daily feed was set at 250 gallons, fed in eight unequal portions over a time range of 7:00 a.m. to 9:45 p.m. The raw sewage used was obtained as before from a special tap in a combined city sewer, pumped to the central dosing tank and fed in order to the individual septic tanks.

Sampling. Samples were composited daily. A representative portion of raw sewage and septic tank effluent was collected at each feed. The raw sewage sample was taken from the central feed tank. The effluent samples were taken from the stirred-up contents of the 55-gallon collecting drums. The portions collected at each feed were taken in proportion to the amount of sewage introduced at that feed and were added to the daily composite bottle and kept refrigerated.

Composite samples. The composite samples of raw sewage and effluents accumulated over a 24-hour period were representative of the volume of sewage fed to the tanks. The procedure adopted here was to composite further samples for the 2-day period from Monday through Wednesday and for the 4-day period from Thursday through Sunday. Samples, after collection, were stored in the refrigerator at 40° F. As previously explained it was found possible to composite up to a week without signifi-



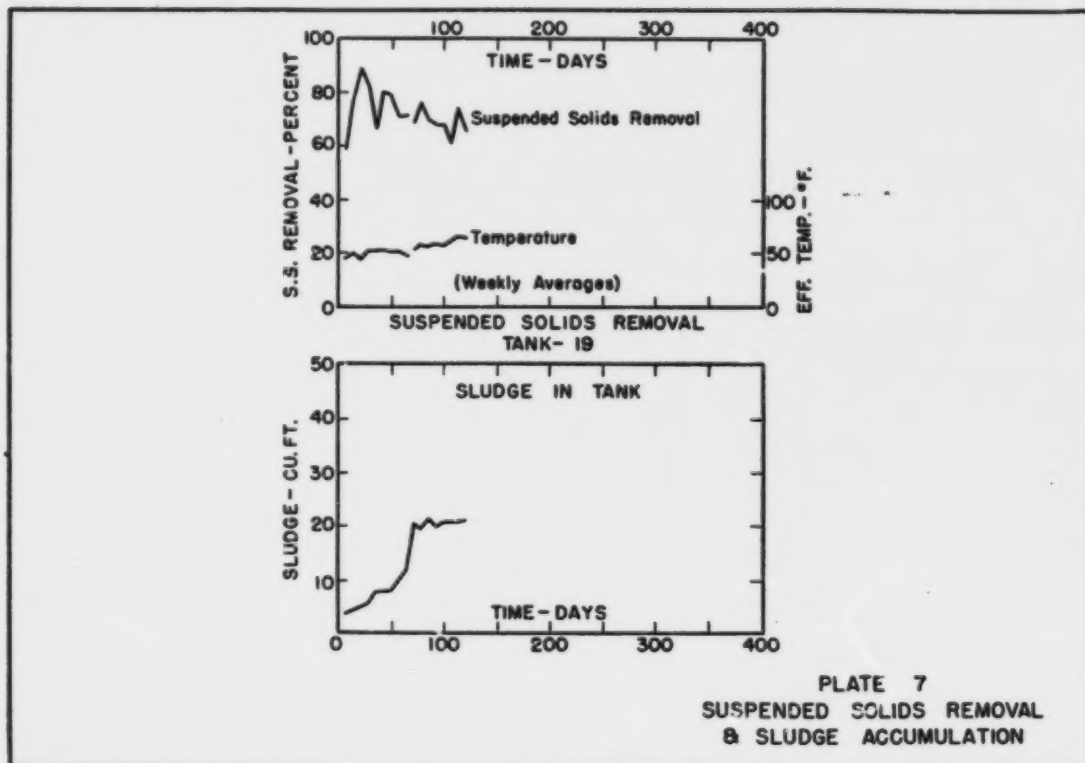


PLATE 7
SUSPENDED SOLIDS REMOVAL
& SLUDGE ACCUMULATION

cant change in suspended solid content, if samples were kept refrigerated.

Sludge measurement. Every Monday morning sludge levels were measured. In tank 9A (one-compartment) nine measurements were made at different locations and these figures averaged to give the average depth. In tank 7A (two-compartment) and tank 19 (three-compartment), three measurements were made in each compartment. Sludge accumulation figures in cubic feet were plotted weekly. After the first 9 weeks of operation, on March 20, 75 gallons of sludge were added to each tank. The operating period from January 17, 1949, to March 20, 1949, is designated as series 7, and that from March 21, 1949 to May 15, 1949, as series 8. Series 7 and 8 includes the entire period from January 17 to May 15.

Results

As before, stress is laid on solids removal data because of effluent disposal to the soil. Data on percentage removal of total solids, total volatile solids, suspended solids and sus-

pended volatile solids were calculated on a weekly basis. Sludge accumulation was plotted on the same basis. Plates 6 and 7 show the comparison between the three rectangular tanks on the basis of suspended solids removal and sludge accumulation for 17 weeks of operation. The sharp increase in sludge between 63 and 70 days is due to the addition of 75 gallons of digested sludge added to age the tanks artificially. Table 6 indicates the manner in which the sludge accumulation is divided between the compartments of the tanks. Tank 19 has maintained the high rate of efficiency longer than either the one-compartment or the two-compartment tank.

In table 7, the over-all averages in parts per million for the raw sewage and the effluents of tanks 3 and 4, 9A, and 19 are presented. These averages are weighted averages, taking into consideration the actual number of gallons added during each day of operation. In table 8 the over-all period is broken down further into series 7 and 8 for the three rectangular tanks. Series 7, as above indicated, ran from January 17, 1949, to March 20, 1949.

TABLE 6.—Sludge accumulation

Compartment.....	Tank 9A	Tank 7A			Tank 19			
		a	b	Total	a	b	c	Total
Week								
Jan. 17 to 23.....	2.8	1.5	1.7	3.2	1.8	0.8	0.9	3.4
Jan. 24 to 30.....		1.9	1.6	3.5	1.9	1.0	1.1	4.1
Jan. 31 to Feb. 6.....								
Feb. 7 to Feb. 13.....	5.0	3.2	2.2	5.4	3.3	1.2	0.9	5.5
Feb. 14 to 20.....	5.5	4.1	2.2	6.3	4.2	2.0	1.4	7.7
Feb. 21 to 27.....								
Feb. 28 to March 6.....	7.0	5.2	3.1	8.4	4.9	1.9	1.0	7.9
March 6 to March 13.....	7.1	6.0	2.7	8.7	6.6	2.2	1.2	10.0
March 14 to 20.....	7.8	6.8	2.5	9.3	7.8	2.4	1.5	11.7
March 21 to 27.....	18.4	16.4	4.0	20.4	15.2	3.4	1.6	20.2
March 28 to Apr. 3.....	17.4	14.4	3.1	17.4	14.0	3.9	1.3	19.2
Apr. 4 to Apr. 10.....	19.2	16.4	3.0	19.4	16.5	4.2	1.9	22.7
Apr. 11 to 17.....	17.6	15.8	3.0	18.8	13.3	4.3	2.0	19.6
Apr. 18 to 24.....	16.6	16.7	3.1	19.8	12.3	5.2	2.9	20.3
Apr. 25 to May 1.....	15.9	17.3	3.8	21.2	12.1	6.0	2.5	20.6
May 2 to May 8.....	15.7	15.6	3.6	19.1	11.7	6.3	2.4	20.4
May 9 to May 15.....	19.6	13.3	4.2	17.5	12.0	6.7	2.9	21.5

Figures represent the cubic feet of sludge in the tank at the end of the week indicated.

TABLE 7.—Sewage and effluent characteristics 250 gallons/day feed January 17—May 15, 1949, series 7 and 8

Item	Raw Sewage	Effluent tanks No.				
		3	4	7A	9A	19
Raw sewage added, gal.....	27,380					
Total solids, p. p. m.....	1,059	762	731	770	778	750
Total solids ash, p. p. m.....	550	502	478	492	506	495
Total solids volatile, p. p. m.....	509	260	253	278	272	255
Suspended solids, p. p. m.....	375	122	96	122	142	102
Suspended solids ash, p. p. m.....	66	32	21	33	41	21
Suspended solids volatile, p. p. m.....	309	90	75	89	101	81
Dissolved solids, p. p. m.....	684	640	635	648	636	648
Dissolved solids ash, p. p. m.....	484	470	457	459	465	474
Dissolved solids volatile, p. p. m.....	200	170	178	189	171	174

NOTE: Tabulated figures are averages weighted on the basis of the number of gallons of sewage fed, and may be used quantitatively to determine the pounds of dry solids going into and coming out of a tank.

Based on solids added with raw sewage only.

At the end of this period additional sludge was added to each tank to provide a measure of the activity of the tanks when there is a greater sludge volume. This second period from March 21, 1949, to May 15, 1949, is labeled series 8. In table 9, these results are expressed as percent removals for total solids, total volatile solids, suspended solids and suspended volatile solids. These figures are directly applicable to the total gallons of sewage added in order to

derive the total pounds of dry solids added and removed from the tanks. On examination, the average removals for the three tanks during series 7 proved to be very close. The average removals for series 8 and for the entire series showed an increase in efficiency of the two-compartment tank over the one-compartment and for the three-compartment tank over the two-compartment. To evaluate these differences properly, it was necessary to make a statistical

examination of these values. As an analysis on the basis of the above averages could not be made because of allowances made for days for which the full 250-gallon feed was not applied, the results were recomputed by individually determining the percent removals of dry solids on each 3-day and 4-day composite. The percent removals thus obtained were averaged and the

standard deviations for the averages were determined. The percent removal figures for series 7 are presented in table 10 and for series 8, in table 11. In table 12 the percent removals and standard deviations are recomputed on the basis of the average of these values. These average percent removals differ slightly from the values obtained in table 9.

TABLE 8.—Sewage and effluent characteristics

Item	Raw		Tank No. 9A 1-compartment		Tank No. 7A 2-compartment		Tank No. 19 3-compartment	
	Series 7	Series 8	Series 7	Series 8	Series 7	Series 8	Series 7	Series 8
Raw sewage added, gal.....	14,808	12,572						
Total solids, p. p. m.....	1,143	960	782	774	792	746	782	714
T. S. ash, p. p. m.....	604	486	533	475	521	459	533	453
T. S. volatile, p. p. m.....	539	474	249	298	270	286	249	262
Suspended solids, p. p. m.....	406	339	96	196	88	163	92	108
S. S. ash, p. p. m.....	63	71	20	66	18	51	18	19
S. S. volatile, p. p. m.....	342	268	76	130	70	112	75	89
Dissolved solids, p. p. m.....	737	621	687	578	704	582	689	606
D. S. ash, p. p. m.....	541	416	513	409	503	408	515	433
D. S. volatile, p. p. m.....	196	206	174	169	201	174	174	174

Series 7—First 9 weeks operation—January 17–March 20, 1949.

Series 8—Second 8 weeks operation after addition of 75 gallons sludge—March 21–May 15, 1949.

NOTE: Tabulated figures are averages weighted on the basis of the number of gallons of sewage fed, and may be used quantitatively to determine the pounds of dry solids going into and coming out of a tank.

Based on solids added with raw sewage only.

TABLE 9.—Percent solids removal efficiencies in percent

Item	Tank No. 9A			Tank No. 7A			Tank No. 19		
	Series 7	Series 8	Series 7 & 8	Series 7	Series 8	Series 7 & 8	Series 7	Series 8	Series 7 & 8
Percent reduction—T. S.....	31.6	19.4	26.5	30.7	22.3	27.3	31.6	25.6	29.2
Percent reduction—T. volatile solids.....	53.7	37.0	46.6	49.8	39.6	45.4	53.8	44.6	49.9
Percent reduction—S. S.....	76.5	42.2	62.1	78.4	51.9	67.5	77.2	68.1	72.8
Percent reduction—S. volatile solids.....	77.9	51.5	67.3	79.7	58.2	71.2	78.1	66.9	73.8

NOTE: These percentages represent the overall performance of the tanks for the series indicated. The percentages are derived from the dry weights of the solids in the raw sewage and in the effluents. The same results may be obtained from the data tabulated on plates 7 and 8, i. e.,

$$\text{Percent removal} = 100 - \frac{\text{p. p. m. effluent}}{\text{p. p. m. raw sewage}}$$

Since some of the percent removal figures were so close together, the next step taken was to obtain the statistical significance of the differences in the efficiencies of the tanks as meas-

ured by the percent removals of solids. To accomplish this, reference was made to Student's Table of "t." The data for suspended solids reduction from table 12 were used and

the examination made as follows (11): the significance of the difference in the average percent removals between the one- and two-compartment tanks; between the two- and three-compartment tanks; and finally, between

the one- and three-compartment tanks, were determined. This was done for series 7, series 8, and for the total series 7 plus 8. The results are expressed in table 13 in terms of significance levels.

TABLE 10.—Statistical data series 7, semiweekly observations, percent removal dry solids

Date	Tank No. 9A (1-compartment)				Tank No. 7A (2-compartment)				Tank No. 19 (3-compartment)			
	T.S.	T.V.S.	S.S.	S.V.S.	T.S.	T.V.S.	S.S.	S.V.S.	T.S.	T.V.S.	S.S.	S.V.S.
1/17-1/19	41.38	59.03	72.51	72.29	38.41	61.06	72.51	75.00	0	1.97	0	2.02
1/20-1/23	27.89	48.11	74.84	77.30	33.15	54.03	72.72	79.23	22.21	36.29	70.30	76.92
1/24-1/26	20.42	37.26	66.84	62.60	22.41	35.79	70.52	60.00	18.42	21.03	72.10	61.73
1/27-1/30	19.67	39.88	82.78	82.38	17.40	29.62	80.73	80.82	20.80	41.59	78.68	77.20
1/31-2/2	50.94	78.16	92.26	93.43	50.24	71.75	91.96	93.96	50.99	79.89	93.05	93.75
2/3-2/6	35.06	69.88	87.89	89.61	34.30	70.85	89.65	92.06	20.72	45.16	82.31	84.41
2/7-2/9	25.02	58.44	71.91	73.85	28.20	60.29	77.23	77.58	28.77	61.59	77.30	78.44
2/10-2/13	46.79	66.16	79.90	80.44	48.34	69.62	83.48	83.39	51.04	72.86	83.17	83.21
2/14-2/16	24.14	39.07	49.72	44.77	25.62	34.15	53.00	52.23	23.34	34.76	55.73	52.23
2/17-2/20	16.61	33.61	74.48	70.34	15.88	38.74	70.78	69.18	15.98	33.61	71.19	70.34
2/21-2/23	21.42	40.90	69.90	70.11	22.80	46.46	77.11	78.54	26.85	54.04	78.99	80.07
2/24-2/27	25.29	55.31	79.86	80.93	0	11.61	79.39	79.00	25.00	55.31	80.15	79.28
2/28-3/3	31.56	52.16	79.19	81.27	35.40	49.01	80.53	80.36	32.93	53.34	81.10	79.90
3/4-3/6	38.03	22.79	66.83	66.14	34.76	7.25	69.94	68.33	45.44	38.08	73.31	71.78
3/7-3/9	16.15	35.46	64.26	65.63	17.17	39.04	74.19	71.51	21.44	44.50	69.72	66.87
3/10-3/13	39.21	58.11	73.84	74.62	39.86	52.06	72.61	73.86	46.66	65.92	70.46	72.34
3/14-3/16	35.67	43.84	58.82	56.61	37.06	48.92	65.03	68.18	36.36	45.23	67.97	65.28
3/17-3/20	25.04	50.29	67.77	68.05	25.75	48.64	68.88	68.37	25.04	50.48	72.50	70.60

NOTE: The per cent removals listed here are used statistically to determine the significance of the differences in efficiency of solids removals by the tanks. In order to agree with the data given in table 9, it would be necessary to weight the data listed here to compensate for the variation in flow and the variation in strength of the raw sewage.

Based on solids added with raw sewage only.

TABLE 11.—Statistical data series 8, semiweekly observations, percent removal dry solids

Date	Tank No. 9 (1-compartment)				Tank No. 7 (2-compartment)				Tank No. 19 (3-compartment)			
	T.S.	T.V.S.	S.S.	S.V.S.	T.S.	T.V.S.	S.S.	S.V.S.	T.S.	T.V.S.	S.S.	S.V.S.
3/21-3/23	35.41	61.15	74.64	73.29	36.84	64.05	70.62	65.96	38.42	64.29	75.45	73.59
3/24-3/27	8.81	7.44	18.03	19.81	22.64	19.86	64.69	64.05	21.61	38.60	62.62	61.29
3/28-3/31	22.13	46.01	49.50	58.15	25.92	48.23	74.75	75.73	24.12	47.84	72.09	69.87
4/1-4/3	24.16	44.85	49.74	64.84	28.14	52.42	76.68	74.54	26.01	50.09	79.79	78.78
4/4-4/6	17.91	38.01	43.72	47.41	21.59	55.93	66.10	62.54	21.06	41.03	70.16	70.22
4/7-4/10	19.62	34.79	44.84	54.64	12.06	18.66	37.61	46.46	22.14	39.40	68.19	66.54
4/11-4/13	18.41	30.71	38.41	44.53	26.01	35.87	55.62	56.30	23.87	42.26	64.23	61.34
4/14-4/17	11.90	28.42	41.71	46.66	22.08	41.11	69.32	71.11	20.69	34.26	69.93	71.11
4/18-4/20	15.80	38.86	50.93	60.30	22.09	40.39	55.27	59.54	22.43	44.75	72.04	70.22
4/21-4/24	16.42	42.44	35.60	50.36	15.64	37.55	28.79	48.17	27.19	48.88	63.46	66.42
4/25-4/27	32.63	49.84	46.80	60.88	29.23	45.13	34.57	53.31	39.96	63.98	67.55	68.45
4/28-5/1	16.92	43.28	37.64	48.85	22.86	43.96	52.94	51.90	25.33	45.33	54.70	55.72
5/2-5/4	35.08	57.45	62.27	64.36	30.56	53.14	49.09	63.82	39.98	60.59	81.81	80.31
5/5-5/8	13.34	35.71	35.19	54.46	13.70	35.71	37.97	52.67	18.62	37.55	63.76	64.28
5/9-5/11	5.03	0	14.07	33.33	17.89	35.82	38.69	52.28	23.71	25.17	71.35	67.82
5/12-5/15	17.70	24.59	42.29	55.34	13.71	17.83	39.01	49.76	12.40	13.24	56.06	56.27

NOTE: The percent removals listed here are used statistically to determine the significance of the differences in efficiency of solids removals by the tanks. In order to agree with the data given in table 9, it would be necessary to weight the data listed here to compensate for the variation in flow and the variation in strength of the raw sewage.

Based on solids added with raw sewage only.

TABLE 12.—Statistical summary, solids data, percentage removals

Item	Tank No. 9A series (1-compartment)			Tank No. 7A series (2-compartment)			Tank No. 19 series (3-compartment)..		
	7	8	7 and 8	7	8	7 and 8	7	8	7 and 8
Percent reduction total solids.....	30.02	19.46	25.05	29.26	22.56	26.11	28.44	25.48	27.04
Standard deviation.....	10.33	8.76	10.88	12.40	6.83	10.58	13.37	7.72	11.02
Percent reduction, total volatile solids..	49.36	36.47	43.29	46.04	40.35	43.36	46.43	43.55	45.07
Standard deviation.....	14.22	16.14	16.28	18.30	13.37	16.19	18.31	13.34	16.05
Percent reduction, suspended solids.....	72.98	42.81	58.78	75.01	53.23	64.76	71.00	68.32	69.74
Standard deviation.....	10.19	14.49	19.56	8.95	15.78	16.62	19.46	7.60	14.94
Percent reduction, suspended volatile solids.....	72.80	52.33	63.16	75.09	59.26	67.64	70.35	67.41	69.02
Standard deviation.....	11.61	12.89	15.89	10.38	9.36	12.64	19.47	18.19	18.94

NOTE: Averages are computed from data listed in tables 10 and 11 and cannot be used in computations involving pounds of solids removed.

The means and the standard deviations of each series had been determined (table 12). The standard error of the difference in the means is then represented by:

$$\sigma_m = \sigma \sqrt{\frac{n_1 + n_2}{n_1 \times n_2}}$$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sigma} \sqrt{\frac{n_1 \times n_2}{n_1 + n_2}}$$

Key

σ_m = Standard error of the difference in the means.

σ = Standard deviation.

n_1 = Number of one series.

n_2 = Number of second series.

$\bar{x}_1$ = Mean of one series.

$\bar{x}_2$ = Mean of second series.

t = Student's "t."

The resulting "t" is then compared with the values in Student's "t" table as used by Fisher (12). The "significance level" is a measure of the percent chance or likelihood that the existing difference might occur by chance alone. Significance levels between 2 and 5 percent are considered significant although barely so. Levels below 1 percent are highly significant. The results expressed in table 13 show significance levels of 53, 43, and 70 percent for series 7. This is an indication that there is no significant difference between the efficiencies of the three tanks for series 7 as measured by percent reduction of suspended solids. For series 8, however, after 75 gallons of sludge had been added to each tank, this situation changed and

significant differences were indicated. The mean percent removals in suspended solids for the one-, two-, and three-compartment tanks in that order are 42.81 percent, 53.23 and 68.32 percent (table 12).

From table 13 it is seen that the significance level for the difference in performance between the one- and the two-compartment tanks is 5 percent; between the two- and the three-compartment tanks it is less than 1 percent; and between the one- and the three-compartment tanks it is also less than 1 percent. In the latter two cases the evidence is conclusive that the three-compartment tank operated at a higher efficiency than either of the other two tanks during series 8. A 5 percent level of significance indicates that once out of 20 times results with a difference as great as these could be obtained by chance if the tanks were both operating at the same efficiency. Therefore, on the basis of this analysis, it cannot be stated conclusively that there was any significant difference in the operation of the one- and the two-compartment tanks. However, if the differences in operation are tested by comparing the differences in the individual readings for each date the picture changes. If there were no difference in the operation of the two tanks during series 8, then the sum of the individual differences taking into consideration algebraic signs should be zero. As this sum is not zero, the problem then becomes one of testing the significance between the mean difference and zero.

When a test of this type is run, the significance level is less than 2 percent indicating that there was a significant difference in the operation of the two plants. This second test for significance is more appropriate for our problem than the first because it rejects any comparisons of the two tanks other than those made on the basis of simultaneous results.

Considering series 7 and 8 together, the suspended solids removal for the one-compartment tank is 58.8 percent, for the two-compartment tank 64.8, and for the three-compartment tank 69.7 percent. These percentages show an increase in efficiency with an increase in the number of compartments. Statistically,

on the basis of this data, a high level of significance can be attached only to the difference in efficiency of the one- and the three-compartment tanks. It is interesting to note that in the original data listed in table 10 the results of the first three days in operation for the three-compartment tank are inconsistent with the remainder of the data. If this first 3-day period were dropped from the results, a significant difference could be demonstrated between the two-compartment and the three-compartment tank as well as between the one-compartment and the three-compartment tank for the total run of series 7 and 8.

TABLE 13.—Significance or probability levels for differences in average suspended solids removal for tanks 9A, 7A and 19—series 7, 8 and 7 and 8

Series	Tank 9A (1-compartment) vs. Tank 7A (2-compartment)	Tank 7A (2-compartment) vs. Tank 19 (3-compartment)	Tank 9A (1-compartment) vs. Tank 19 (3-compartment)
7.....	0.53	0.43	0.70
8.....	*0.05	Less than 0.01	Less than 0.01
7 and 8.....	0.178	0.206	Less than 0.01

* Analysis of differences of individual results indicate significance at 2 percent level.

Thus, after the addition of sludge and the start of series 8 the tanks showed a significant difference in their levels of operation, with the efficiency of suspended solids removal increasing as compartments were increased. These results are indicative; however, they must be interpreted with care. The study has been conducted thus far over a small period of time and although a difference in performance has developed there is no conclusive evidence as yet that the difference is due to compartmentation or even that the difference is permanent in nature. This experiment on compartmentation is being continued and further results will be published in subsequent reports.

SUMMARY

1. A review of the literature on household septic tank compartmentation indicates technical credence, but a hesitancy in recommending

it in this country not evident in foreign literature. Little unity of thought with respect to design shape, size, arrangement and number of compartments is found.

2. In this country the few design recommendations run to rectangular shapes; foreign designs, to both rectangular, and series or segmented cylindrical shapes. Sizes as small as 15 gallons per capita where sewage flows are 5 g. p. c. d. are mentioned; theoretical detention capacities of 2 and 3 days are common, with thoughts running to longer periods in a few instances. Both small and large first-compartment recommendations are found, with preponderance of the latter. Recommendations found on number of compartments ranged from two to four.

3. Experimental- and survey-type studies found were limited to two, an experimental study at the University of Illinois and an examination of survey data on a considerable number of tanks in Victoria, Australia. In both

cases compartmentation was found technically advantageous; in both cases a large first-compartment was preferred over equal compartments. The Illinois study was confined to rectangular shapes; the Australian study may have included some round shapes.

4. A previous report on this project, "Studies on Household Sewage Disposal Systems," Part I, 1949, includes the results of experimental operation of 18 septic tanks of single- and multi-compartment design. A year's simultaneous operation of 5 single-compartment cylindrical, rectangular and oval tanks of approximately 500 gallons capacity, a 553-gallon two-chamber tank, a 673-gallon four-chamber tank and a 2,060-gallon single-chamber tank, indicated little difference in average suspended solids removal performance among the 5 single-chamber varishaped tanks of about the same capacity, but considerably higher performance for the two- and four-chamber tanks and for the large single-chamber tank, on the suspended solids removal basis. The average suspended solids removal efficiencies for the year's run, with sludge added to the tanks at intervals, to stimulate accumulations over several years of normal operation, fell between 59 and 65 percent for the 5 single-chamber tanks of about the same capacity, and were 78, 84 and 82 percent respectively for the 3 remaining tanks, in the order above mentioned.

5. A study of experimental operation of single-, double-, and triple-chamber tanks, each within the Joint Committee 500-gallon rectangular tank shell is being made. The average suspended solids removals for the 4-month period, January 17 to May 15, 1949, were 59, 65 and 70 percent for the one-, two-, and three-chamber tanks respectively. The results of the two experimental runs made during this period indicate little difference in average suspended solids removals among the three for the first run, developing into significant differences with the

addition of sludge for the second run. Performance appeared to improve with the increase in number of compartments during this run. Operation is being continued. Recent data being accumulated indicate variation in performance and warrant caution against premature conclusions on the basis of the early results above mentioned.

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SECTION B

Experimental Studies of Tank Inlets, Outlets and Intercompartment Appurtenances

INTRODUCTION

Household septic tank design recommendations in this country, as well as information available from several foreign sources, indicate a variety of inlet, outlet and intercompartment appurtenance arrangements.

Inlets

Inlet designs include pipe tees, bends, and wyes, and baffling arrangements ranging from small inlet enclosures to baffles extending across the tank. Combinations of pipe fittings and baffles are also found. Some instances of the elimination of inlet appurtenances occur, notably in four States in this country, in which the design recommendations provide for the passage of the sewage through the wall directly from the sewer at a point above the water level in the tank. The use of piping outside the tank to permit entry of sewage below the water line, without internal fixtures, is noted in the foreign literature.

A review of State publications at hand indicates a range from about 2 to 26 inches submergence of the inlet pipe fitting or baffle, with preponderance of pipe fittings at 12-inch submergence, and baffles mostly 18 inches or more. The Joint Committee recommends 12-inch submergence for pipe tee or baffle type inlets, at least 6-inch projection above water level and a 3-inch drop from sewer invert to water level. The same review has shown that the distance between the influent-pipe invert and the water level varies between 0 and 4 inches, with the inlet-fixture projection above the water level ranging from 3 to 18 inches.

Outlets

State recommendations on outlet designs in this country favor the pipe tee or baffle, with a

specification of one or the other in most cases, and a choice in others. In some few cases a pipe bend, or a baffled pipe bend is recommended, and, in a few others, a combination of a pipe wye and one-eighth bend. The external inlet piping arrangement mentioned above, from a foreign source, was also applied to the outlet, the sewage leaving through an opening in the downstream wall below the water line, thus eliminating internal appurtenances. Submergence of pipe or baffle outlet devices in State recommendations ranges from 4 to 24 inches, with penetration of outlet pipes or baffles largely centered in the 12-inch through 18-inch bracket. The projection of outlet fixtures above water level ranges from 3 to 12 inches. The Joint Committee recommends either pipe tee or baffle, at 15- to 18-inch submergence in either case, with at least 6-inch projection above the waterline.

Intercompartment Appurtenances

Intercompartment appurtenance arrangements found in the literature include pipe fittings and submerged single or multiple openings in compartment walls, with or without baffling devices. The vertical location of such openings is generally at or above mid-depth. Designs with openings at both the lower and upper sections of the liquid depth have been found. Some use has been made of the weir and baffled weir in intercompartment arrangements. Both "over and under" and "under and over" baffling arrangements are used.

Limited information available on two previous experimental studies of inlet devices for small septic tanks is also of interest and is reported below.

Four types of inlets were investigated at the University of Minnesota in 1924, in a small experimental tank provided with glass observation windows. The inlets examined were the

simple elbow, an elbow and a transverse tee, baffleboards, and a current-breaker box (a rectangular box discharging to tank through two submerged ports). The elbow and the baffleboard designs were reported unsatisfactory, producing a great deal of agitation and carrying sludge away from the inlet, with uneven distribution. The combination bend and tee, and the current-breaker box, were reported to provide very satisfactory results.

In about 1920, the Michigan Department of Health conducted experiments on a standard-size tank, equipped with a glass side, using dye to trace currents under various inlet, outlet, and baffle arrangements. Although the details are not available, it is of interest that the study influenced the department to eliminate inlet devices of any type. Sewage enters the tank directly from the sewer about $2\frac{1}{2}$ inches above the water line in the Michigan design.

Aside from the experimental comparison of a weir outlet and a tee outlet during the earlier work of this Project (reported in Part I, "Studies on Household Sewage Disposal Systems, 1949"), no information on other factual investigation of outlet characteristics has been found. Neither has information on the experimental study of intercompartment flow appurtenances been found in the literature.

CURRENT STUDY

The practical usefulness of any particular type of inlet, outlet and intercompartment appurtenances depends on its effectiveness throughout a range of sludge and scum accumulation circumstances developing between tank cleaning intervals.

In considering the study of these appurtenances it was considered desirable to set up full-sized tanks for such study, and to carry the operation under various appurtenance variables through the full range of sludge accumulations, together with such scum circumstances as may develop under experimental circumstances.

Because such a program is of necessity of long duration it was felt that in starting the study valuable information might be developed through a series of short run tests utilizing a dye tracer and examining detention characteristics and flow patterns under the various inlet, outlet, and intercompartment circumstances.

The status account of the studies, reported below, is essentially an examination on detention characteristics under several inlet and intercompartment arrangements tried thus far, utilizing a duplicate tank equipped with Joint Committee-type pipe fitting appurtenances as a control, under zero sludge and scum accumulation circumstances—essentially those of a tank being put into service for the first time after cleaning.

As before mentioned, longer runs under various sludge accumulation circumstances, with assembly of data on both detention and solids removal, are intended. Investigation of possible correlation between detention and solids removal under intermittent flow circumstances will also be made, with a view toward utilization of the short-period detention test as a rapid performance test.

Description of Tanks

Four septic tanks were built for the study of inlets, outlets, and intercompartment flow appurtenances. All are rectangular and identical as to the over-all inside dimensions, namely 3 feet wide by 6 feet long, with a 4-foot water depth. One pair, identified as tanks 17A and 18A, operate as single-compartment tanks. The other pair, identified as tanks 15A and 16A, operate as three-compartment tanks, each formed by the insertion of 2-inch-thick, watertight, transverse, wooden partitions at the third points. The control tanks, 17A and 18A, are equipped with 4-inch vitrified pipe tee inlets and outlets, and compartmented tank 15A also has a 4-inch vented Ω -bend (two $\frac{1}{4}$ bends) intercompartment fittings. The two test tanks, 18A and 16A, operate under experimental arrangements of inlet, outlet and intercompartment devices. The control tanks are identified in table 1 and plates 1, 25 and 29. The other two, identical except for the variable under study, are further described in the specific study.

Investigation of two types of inlet and two intercompartment appurtenances, on the basis of their effect on flow detention characteristics, has been made thus far. In addition, the opportunity was taken to make dye runs on a number of other tanks which are also in operation.

Through examination of the effluent pattern of tanks, utilizing a dye or other suitable medium as a tracer, a picture of the flow, detention and dispersion characteristics can be obtained, and a comparison of tanks may be made on this basis. The significance of performance on this basis to the performance of tanks with respect to suspended solids removal has not been established at this time. Such study will be made when sufficient data on both bases are available for a statistical analysis. In advance of such study it is of interest to note in the limited work done thus far, and reported in detail later on, that experimental detention times (at the one point investigated) in tanks of the same size and shape, and equipped with the same pipe fitting flow appurtenances, were increased considerably upon compartmentation, and further, that experimental detention times increased as the number of compartments were increased. This is of particular interest as the experimental work on suspended solids removal efficiencies thus far has indicated trends toward higher removals in compartmented tanks.

Thus, there appears to be good reason to investigate possible correlation between the experimental detention times and performance on a suspended solids removal basis in small septic tanks, even though they are far beyond the short periods considered adequate in larger tank practice for settlement of settleable solids. However, other than the trends above mentioned, which are based on limited data, a correlation, if any, is not yet established.

Methods

In the test procedures applied here, a tracer medium, in this case the water-soluble dye, uranin, was added to one of the eight intermittent doses making up the daily loading on a particular tank, and the quantities of the dye in the effluents discharged thereafter for the duration of the test were determined. The cumulative amounts of dye recovered, either in grams or as a percent of the total amount recovered, when plotted against the cumulative flow or time, trace a dispersion curve of basically an S-shape. For practical purposes, the observations are discontinued at a point where further time or flow causes little or no change in the amount of tracer recovered. In these

experiments recoveries ranged from 80 to 90 percent of the dye added.

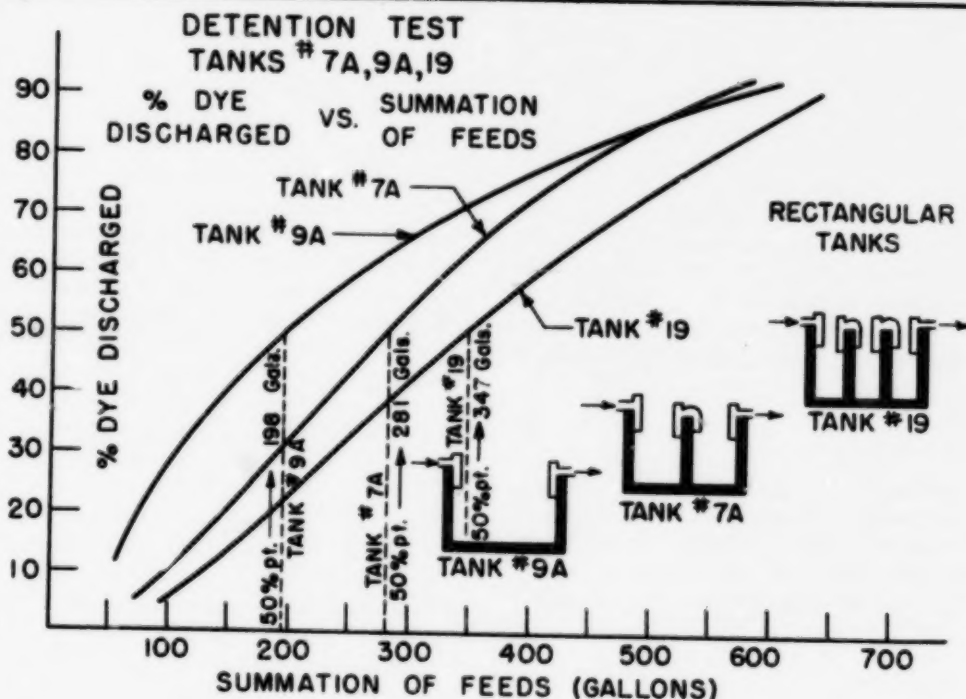
In operation, the uranin dye was added to the sewage placed in the control dosing tank for the mid-day dose (either the 1:30 p.m. or the 4:00 p.m. dose) and allowed to mix thoroughly before dosing the tanks. Samples were then taken from the effluent drums after each subsequent dose until effluent concentrations had dropped off to little or no dye. A check run was started as soon as possible after the first run was completed.

Effluent samples were analyzed for dye concentration through use of a Beckman Photoelectric Spectrophotometer, Model DU, and a density *vs.* concentration (0 to 1.0 p. p. m.) calibration curve developed for the uranin dye used in these tests. The density readings were taken at a wavelength of 490 millimicrons using a tungsten filament bulb as the light source.

Correction for light absorption by the sewage itself was made through use of readings on effluent blanks taken before the dye runs. All samples, including the effluent blanks, were clarified by coagulation with zinc sulfate and sodium hydroxide, sedimentation and filtration, to avoid turbidity interference (in later work a turbidity correction is also made). The clarification had a negligible effect on the dye concentration.

A plot of percent dye discharged against the summation of sewage doses was found to be the most practical method of working with the data. A regression line was fitted through the data for each tank by using a 5-point moving average in preference to other methods because of the skewness of the dispersion curve. The comparisons made of experimental detention times are based on simultaneous runs. Some variation in curve shapes might be expected from independent runs.

For the purposes of this study the "experimental detention flow" is the total volume of sewage discharged from the tank up to the point at which 50 percent of the total amount of dye recovered during the test had been discharged. The "experimental detention time" is the elapsed time from the application of the dye to the intermittent discharge during which the 50 percent point occurred. The "coefficient of dispersion," the relative measure of spread of the dispersion curve, is expressed as the ratio



SAMPLE COMPUTATIONS

TANK # 7A

VALUES TAKEN FROM CURVE

% DYE DISCH.	Σ OF FEED
50	281
20	148
80	452

EXP. DETENTION TIME

ON RUN #1 (STARTED AT THE 1:30 P.M. FEED, APRIL 27) THE 281st. GAL. WAS DISCHARGED FROM TANK #7A DURING THE 1:30 P.M. FEED (APRIL 28), WHICH WAS 24.00 HOURS AFTER THE START OF THE RUN.

ON RUN #2 (STARTED AT THE 4:00 P.M. FEED, MAY 6) THE 281st. GAL. WAS DISCHARGED FROM THE TANK DURING THE 6:15 P.M. FEED (MAY 7), WHICH WAS 26.25 HOURS AFTER THE START OF THE RUN.

$$\text{EXP. DETENTION TIME} = \frac{24.00 + 26.25}{2}$$

$$= 25.13 \text{ HOURS}$$

CO-EFFICIENT OF DISPERSION
(C.D.)

$$= \frac{\Sigma \text{ OF FEED AT WHICH } 80\% \text{ OF DYE DISCHARGED}}{\Sigma \text{ OF FEED AT WHICH } 20\% \text{ OF DYE DISCHARGED}}$$

$$= \frac{452 \text{ GALLONS}}{148 \text{ GALLONS}}$$

$$= 3.05$$

PLATE 8

of the total sewage discharged up to the 80 percent dye discharge point, to the total sewage discharged up to the 20 percent dye discharge point. As dosages are intermittent, and as experimental detention times are taken as elapsed time to a particular dose, the corresponding experimental detention flow may vary within the volume of the particular dose (discharge). Intermittent doses ranged from 25.0 to 37.5 gallons under the 250-gallon per tank per day loading applied in these tests.

A sample computation of experimental detention time and coefficient of dispersion is shown in plate 8.

Results

The results of test runs on two inlet arrangements in the single-compartment-type tank, and two intercompartment flow arrangements in the three-compartment-type tank are presented under "Series A" and "Series B" following:

SERIES "A"

Series "A" concerns two runs each on the two single-compartment tanks, 18A and 17A, and on the two three-compartment tanks, 16A and 15A. All four tanks operated simultaneously on each of the two runs, and the results shown in table 16 and plate 9 for each tank are the composites of the two runs.

In this trial, single-compartment tank 18A was fitted with a plain 4-inch sewer inlet in the center of, and flush with, the influent wall, with the invert 3 inches above water line. The influent sewer grade was 2 percent. In other respects the tank was identical to the tee-fitted control tank, 17A.

The results in table 16 and plate 9 indicate that experimental detention flows and times were essentially the same for both the plain 4-inch-inlet-equipped tank, 18A, and the 4-inch-tee-inlet-equipped tank, 17A. The coefficient of dispersion for the tee-inlet control tank, 17A, was lower (better) than that of the plain-inlet tank. For essentially equal experimental detention flows and times, the tank providing the

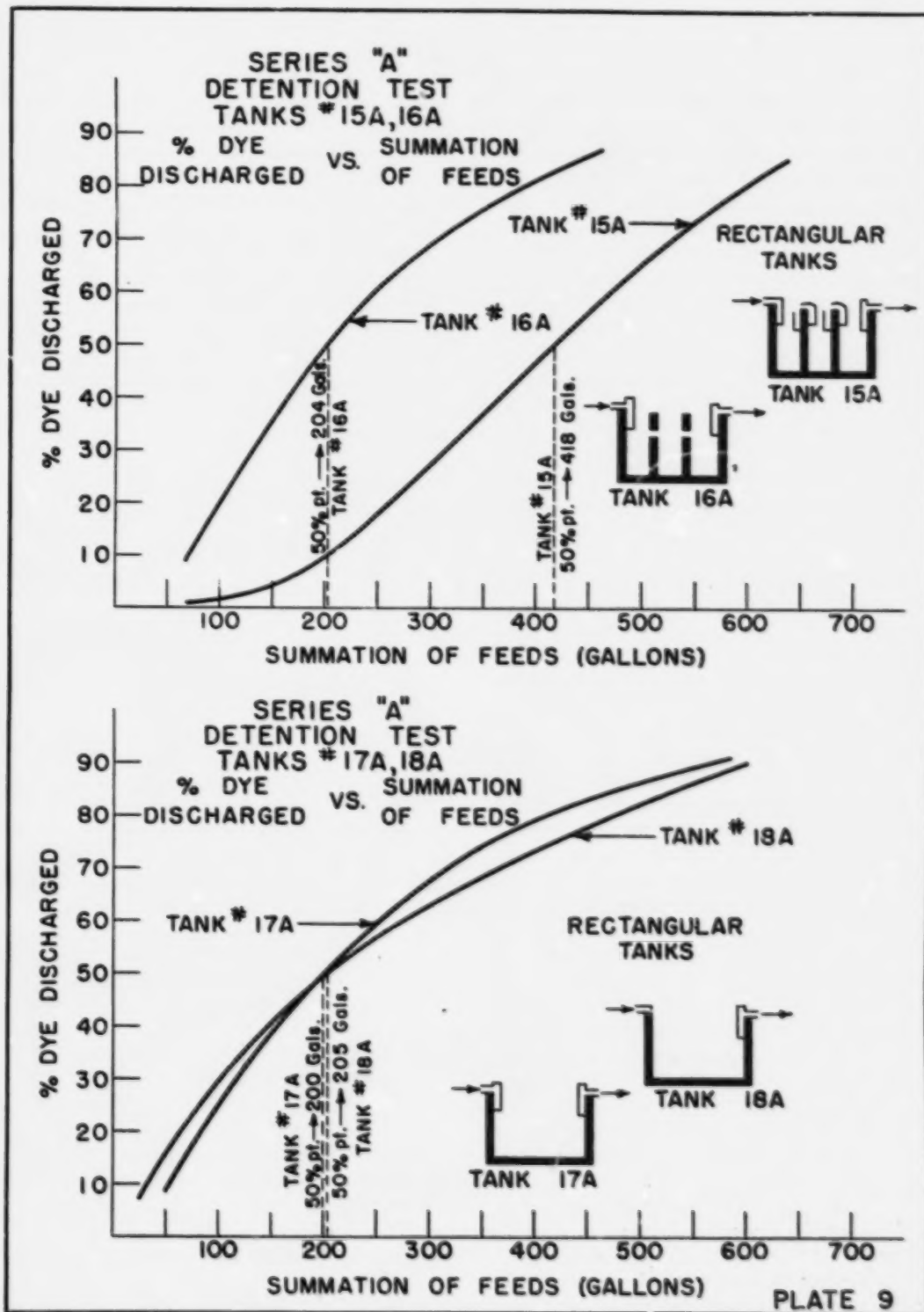
lower coefficient of dispersion would be considered to have the better flow pattern.

The intercompartment arrangement tested during his series concerned a 4-inch-high horizontal slot extending the width of the tank (3 feet), with top of slot submerged 12 inches, in each of the two partitions of tank 16A. This arrangement is compared with the 4-inch vented Ω -bend intercompartment arrangement of control tank 15A. Both tanks have tee inlets and outlets. The results in table 16 and plate 9 indicate that with 12-inch submergence of the slots, tank 16A provided only one-half the experimental detention flow, and less than one-half the experimental detention time, of the Ω -bend-equipped control tank, 15A. The Ω -bend-equipped tank had the lower (better) coefficient of dispersion.

Since all four tanks were dosed identically with the same sewage and operated simultaneously, a comparison of detention characteristics of the two single-compartment tanks and the two triple-compartment tanks may be made. It is of interest to note that the slotted partition, three-compartment tank, 16A, with the slots at 12-inch submergence, provided essentially no larger experimental detention time and flow than the single-compartment tanks, 18A and 17A, with plain and tee inlets respectively, although its coefficient of dispersion was better. It should be borne in mind that this refers to a 4-inch slot at 12-inch submergence. Other slot circumstances will be investigated.

TABLE 16.—Detention characteristics series "A"

Tank No.	Exper. det. flow—gal.	Exper. det. time—hrs.	Coef. of dispersion	Remarks
Single-compartment tanks (variable-plain inlet)				
18A.....	205	19.50	7.42	4" dia. plain inlet
17A (control).....	200	18.50	4.91	4" tee inlet
Three-compartment tanks (variable-slots in partitions)				
16A.....	204	19.25	3.79	4" slot, 12" sub.
15A (control).....	418	41.25	2.27	4" vented Ω -bend



SERIES "B"

Two changes in the variables under study in the four tanks reported under series "A" were made for the series "B" trial. A baffle was added to the plain pipe inlet of single-compartment tank 18A, and a 4-inch-diameter hole in each partition of the three-compartment tank, 16A, replaced the previous slot arrangement. All other details of design and operation were the same as outlined previously. Two runs were made, all four tanks were operated simultaneously and the results are the composites of the two runs.

The baffle added to the plain inlet in single-compartment tank 18A was located 12 inches from the influent wall, extended laterally the tank width and vertically to 12 inches below the water line. As previously mentioned, the inlet behind the baffle was a 4-inch sewer on a 2 percent grade, its end flush with the influent wall and the invert 3 inches above the water line.

The results in table 17 and plate 10 indicate that the experimental detention times of both baffled inlet tank 18A and control tank 17A were the same. Control tank 17A provided a slightly larger experimental detention flow but not quite as good a coefficient of dispersion as baffled inlet tank 18A. Thus, it appears that the baffled pipe inlet and the tee inlet were essentially equal in effect on detention behavior of the type of tank in which the trials were made, and at the one operating circumstance investigated, that is, without sludge accumulation. Investigation of performance over a range of sludge accumulation circumstances is intended.

Considering the intercompartment hole arrangement investigated in the three-compartment tank, 16A, during this series, the single hole in each of the two partitions was 4 inches in diameter, located in the center transversely and submerged 12 inches to the top of the hole.

Referring to the results in table 17 and plate 10, it will be seen that the experimental detention characteristics of partition hole-equipped tank, 16A, approached much closer those of partition Ω -bend-equipped control tank, 15A, than did the same tank (16A) when equipped with partition slots in the series "A" runs. As both holes and slots were located at the same elevation in their respective runs the improvement in tank detention characteristics must have been

caused by the constriction of the intercompartment opening. As for detention performance of the hole-equipped tank, 16A, as compared to tee-and-bend-equipped control tank 15A during series "B", it is of interest to note that the experimental detention flows and times of tank 16A were about 82 and 88 percent, respectively, of those of control tank 15A. The coefficient of dispersion for control tank 15A was lower (better) than that of tank 16A.

It might be noted here that in both series "A" and series "B" the three-compartment tanks provided equal or larger experimental detention flows and times, and in all cases lower (better) dispersion characteristics, than did the single-compartment tanks of essentially the same capacity.

TABLE 17.—Detention characteristics, series "B"

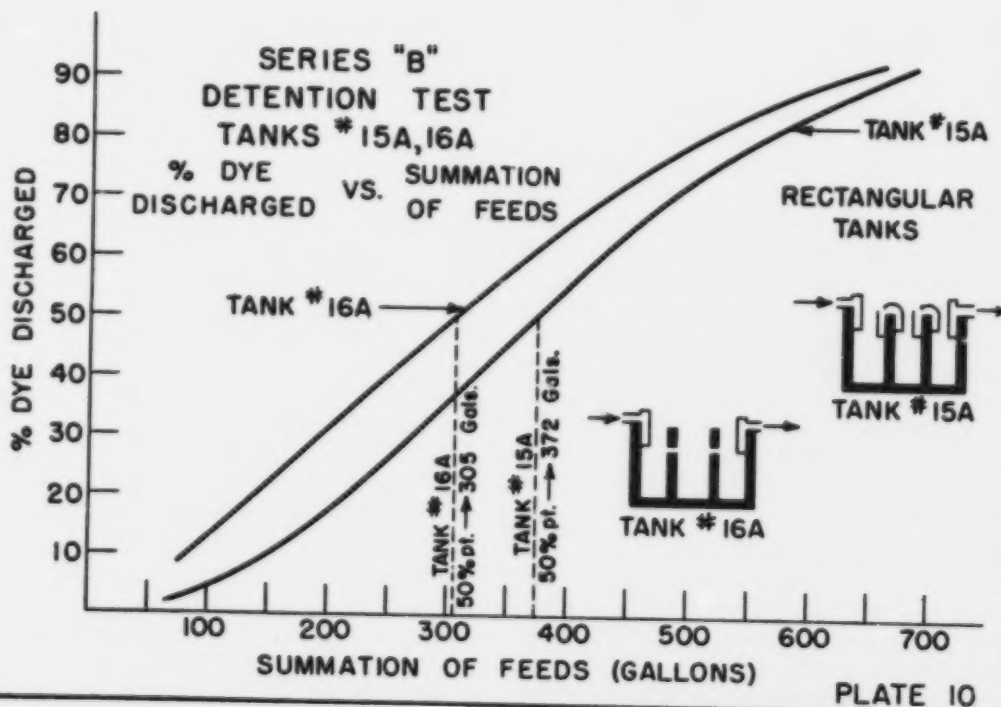
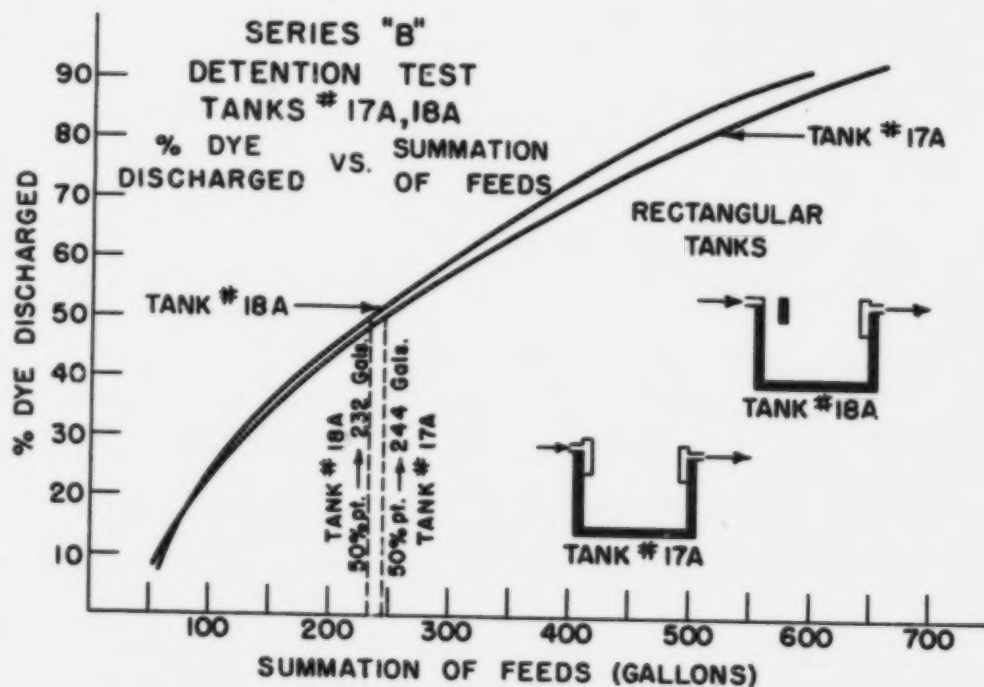
Tank No.	Exper. det. flow—gal.	Exper. det. time—hrs.	Coef. of dispersion	Remarks
Single-compartment tanks (variable-inlet)				
18A.....	232	22.75	5.28	Baffled 4" inlet
17A (control).....	244	22.75	5.63	4" tee inlet
Three-compartment tanks (variable-cir. holes in partitions)				
16A.....	305	27.63	3.62	4" hole, 12" sub.
15A (control).....	372	31.50	2.52	4" Ω bend

One-, Two-, and Three-compartment Tanks 9A, 7A and 19

Two dye runs each were made on the one-, two-, and three-compartment tanks 9A, 7A, and 19 identified earlier in this report. Although the data available on detention characteristics at this time represent but one of a series of dye runs to be made from time to time under increasing sludge accumulations, the partial results are of interest.

The dye runs were made during the regular operation of these tanks in carrying on studies of compartmentation. Each of the dye runs was carried out simultaneously on the three tanks and the results shown in table 18 are composites of the two runs.

It is of interest to note that the trend ob-



served in the previously discussed series "A" and series "B" runs, namely, that the subdivision of the tank into compartments, within the limits of the particular trials, resulted in an improvement of detention characteristics, was also observed in the runs on the three tanks concerned here, and further, that the improvement in detention characteristics progressed as the number of compartments increased from one to two to three. All of these tanks had 4-inch tee inlets and outlets and 4-inch tee and elbow partition fittings.

TABLE 18—Detention characteristics, tanks 9A, 7A and 19

Tank No.	Exper. det. flow—gal.	Exper. det. time—hrs.	Coef. of dispersion	Remarks
9A.....	196	20.50	5.61	Single-comp.
7A.....	281	25.13	3.05	Two-comp.
19.....	347	33.88	2.92	Three-comp.

SUMMARY

1. A review of available literature on residential septic tank appurtenances indicates the following:

Inlets.—Pipe tees and baffles are common recommendations, with bends, wyes or combinations being less common. Four States recommend a plain sewer inlet entering above the water line. An external tee-and-bend permits a plain inlet above mid-depth in a foreign design. Projection of fixtures below water line ranges from 2 to 26 inches in several State recommendations. Projection above water line ranges from 3 to 18 inches. The drop from sewer invert to water line ranges from 0 to 4 inches. The Joint Committee recommends 12-inch projection below and at least 6 inches above the water line, and a 3-inch drop from the inlet sewer to the water line.

Outlets.—Most States favor the pipe tee or baffle outlet, with bends, wyes and combinations less common. The foreign external tee and bend inlet arrangement, mentioned above, was also applied to the outlet. Projection of fixtures ranges in several States from 4 to 24 inches

below and 3 to 12 inches above water line. The Joint Committee recommends a 15-inch to 18-inch projection below, and at least 6 inches above the water line.

Intercompartment flow appurtenances.—Pipe fittings and single- and multiple-partition openings, with and without baffles and weirs, have been suggested in literature. Partition openings are generally at or above mid-depth. Some "over and under" and "under and over" arrangements are found, also openings in both top and bottom sections of a partition.

2. Two previous experimental studies of inlets are known, although details are not available. The University of Minnesota experimented with four types of inlets in a small experimental tank, equipped with glass windows, reporting a **combination bend and transverse tee**, and a **current-breaker box**, to be satisfactory. Pipe bend and baffleboard designs were reported unsatisfactory. The Michigan Department of Health experimented with inlet, outlet and baffle arrangements, using a dye tracer, and, as a result, eliminated inlet appurtenances from department recommendations, the sewage entering directly from the sewer about 2½ inches above the water line.

Two single-compartment tanks and two three-compartment tanks (each in the Joint Committee 3- by 6- by 4-foot water depth, 500-gallon-type shell) were constructed for study of inlets, outlets and intercompartment appurtenances. One of each type of tank was equipped with Joint Committee-type tee inlets, outlets, and Ω -bend intercompartment fittings, and the other was equipped identically except for the particular variable under study. Exploratory tests of tank detention characteristics under various inlet, outlet and intercompartment arrangements, using uranin dye as a tracer, are being made. These will be followed by suspended solids runs under various sludge accumulations.

4. Experimental dye runs in the pair of 500-gallon single-compartment Joint Committee-type tanks, without sludge accumulation, resulted in the following:

(a) The tank equipped with a plain 4-inch sewer inlet, 3 inches above the water line, provided essentially the same experimental detention time as the 4-inch-tee-inlet-equipped control tank. The latter, however, had a lower

coefficient of dispersion and therefore a somewhat better flow pattern for approximately the same experimental detention time.

(b) The addition of an inlet baffle to the plain sewer inlet above mentioned improved the flow pattern as indicated by the lower coefficient of dispersion. The experimental detention times for both the baffled-inlet tank and tee-inlet control tank were the same.

5. Similar dye runs on a pair of 500-gallon rectangular, three-compartment tanks, without sludge accumulation, resulted in the following:

(a) The tank equipped with a 4-inch horizontal slot extending to tank width in each partition, submerged 12 inches to top of slot, resulted in an experimental detention time essentially equal to that of an equal-size single-compartment tank, but less than half that of the Ω -bend-equipped three-compartment control tank. The coefficient of dispersion of the slotted-partition tank was somewhat better than that of the single-chamber tank but not as good as that of the Ω bend partition-equipped control tank.

(b) A 4-inch-diameter hole, substituted for the slot above mentioned in each partition, centered transversely and submerged 12 inches to top of hole, extended the experimental detention time, as compared to the control, over that provided by the slotted tank, in relation to its control in the previous test. A slight improvement in the coefficient of dispersion was also noted.

(c) It appears, therefore, that for 12-inch submergence, and without sludge accumulation, the detention characteristics of the slotted-partition, three-compartment tank were considerably below those of the Ω -bend-equipped, three-compartment control tank, while those of the circular-hole-equipped tank approached those of the control tank. Detention behavior under other circumstances of partition slot, hole, and pipe fitting sizes, locations and sludge accumulations has not yet been investigated.

6. A comparison of the experimental detention characteristics of the pipe-fitting-equipped single- and three-compartment control tanks above-mentioned, which were of essentially equal over-all capacity and shape, indicated improvement in detention characteristics through compartmentation, at the zero sludge accumulation point.

7. A comparison of experimental detention characteristics of pipe-fitting-equipped single-, double-, and triple-compartment rectangular tanks, all of essentially equal over-all capacity and shape, indicates progressive improvement of detention characteristics as the number of compartments increased from one to two to three, at the one sludge accumulation circumstance under which the test was made. Observation of behavior at other sludge accumulation levels is intended.

SECTION C

Field Studies of Possible Modifications of the Percolation Test Method

INTRODUCTION

Percolation tests have been successfully employed in many cases as a quantitative measure of the water absorption characteristics of soils. Musgrave (1,2) used percolation tests (infiltration tests) successfully in studying agricultural behavior of soils (i. e., run-off and erosion characteristics). Vanatta and Uhland (3) show that percolation rates, obtained by measuring the rate of water absorption from holes dug in a variety of soils at a variety of depths, correlate very well with estimates of soil permeability made by different and independent methods such as visual inspection, pore space analyses, and soil histories.

In the sewage work field, Henry Ryon (4,5) in about 1927 developed and successfully used a percolation test to estimate water absorption characteristics of soils on which to base designs of subsurface leaching fields. This method of Ryon's for making percolation tests has since become universal, some variation of the test being recommended by many of the State health departments and by the Joint Committee on Rural Sanitation. As a tool for estimating water absorption characteristics of soils for design of subsurface sewage disposal systems, it has undoubtedly been valuable in many cases. However, it is believed that a few modifications can be suggested for its improvement.

Although the present percolation test specifications are relatively simple, a further simplification would be advantageous. The method of making percolation tests as recommended by the Joint Committee (6) is as follows: "Excavate a hole 1 foot square and to the depth of the proposed disposal trenches. * * * Fill the hole with water to a depth of at least 6 inches and allow this water to seep away. Judgment is required in determining how soil conditions at time of test vary from year-around average conditions. Where soil appears exceptionally

dry, or where soil conditions are questionable, greater depths of water may be used or the test may be repeated. * * * Observe the time in minutes required for the water to seep away completely. This time divided by the total number of inches of water placed in the hole gives the average time required for the water to drop 1 inch. * * *".

The test as specified involves a number of objections. Digging the 1-foot square hole is time-consuming and in many soils it is difficult to dig a hole to the specified size with any accuracy. Also no provision is made in the specifications for the replicating of tests in the proposed soil area. It is suggested that a smaller hole, preferably a 4-inch hole dug with a post-hole auger, might be substituted for the larger square hole. An auger hole is easier to dig, takes less time to dig, and will be easier to maintain to a constant size. The auger hole will also require a smaller volume of water for the actual percolation test. It should be possible therefore, to make several percolation tests in an auger-type hole in the same time, with the same labor, and with the same volume of water that it would require for one percolation test in the 1-foot square hole. This would allow a replication of tests, which is highly desirable, with no increase in time or labor involved.

A replication of percolation tests in any tile field area being planned will give a more accurate estimate of soil absorption characteristics than a single measurement. In fact a replication of tests is almost a necessity because of the possible wide variations in such percolation measurements. Variations can be due to inherent soil variations, prior soil moisture conditions, and variations due to measuring methods. An average of several replicates will tend to discount these uncontrollable variations and give a more reliable estimate of soil absorption characteristics over any specific area.

A question arises as to the comparative rates

obtained in different-sized and different-shaped holes. A preliminary investigation has been made of this point and will be discussed later.

Another suggestion for the possible improvement of the percolation test concerns the technique in running the test. Present specifications are quite loose concerning the saturation of the soil in the percolation test hole. Prior soil moisture conditions can have a tremendous effect on test results. A test made in early spring when the soil has been saturated over a long period of time is likely to give quite different results from a test made under dry summer conditions unless particular attention is paid to approximating conditions of saturation in every test. Not only does the soil need to be saturated, it must be kept saturated long enough for the soil colloids to swell and come to equilibrium conditions. This is particularly necessary in soils containing any quantities of clay. It is therefore suggested that percolation tests should be made over a 2-day period. The holes can be dug 1 day, kept filled with water and left to soak overnight. The holes should then be refilled the next day and test measurements made. In sandy or silty soils the overnight soaking period will probably not be necessary.

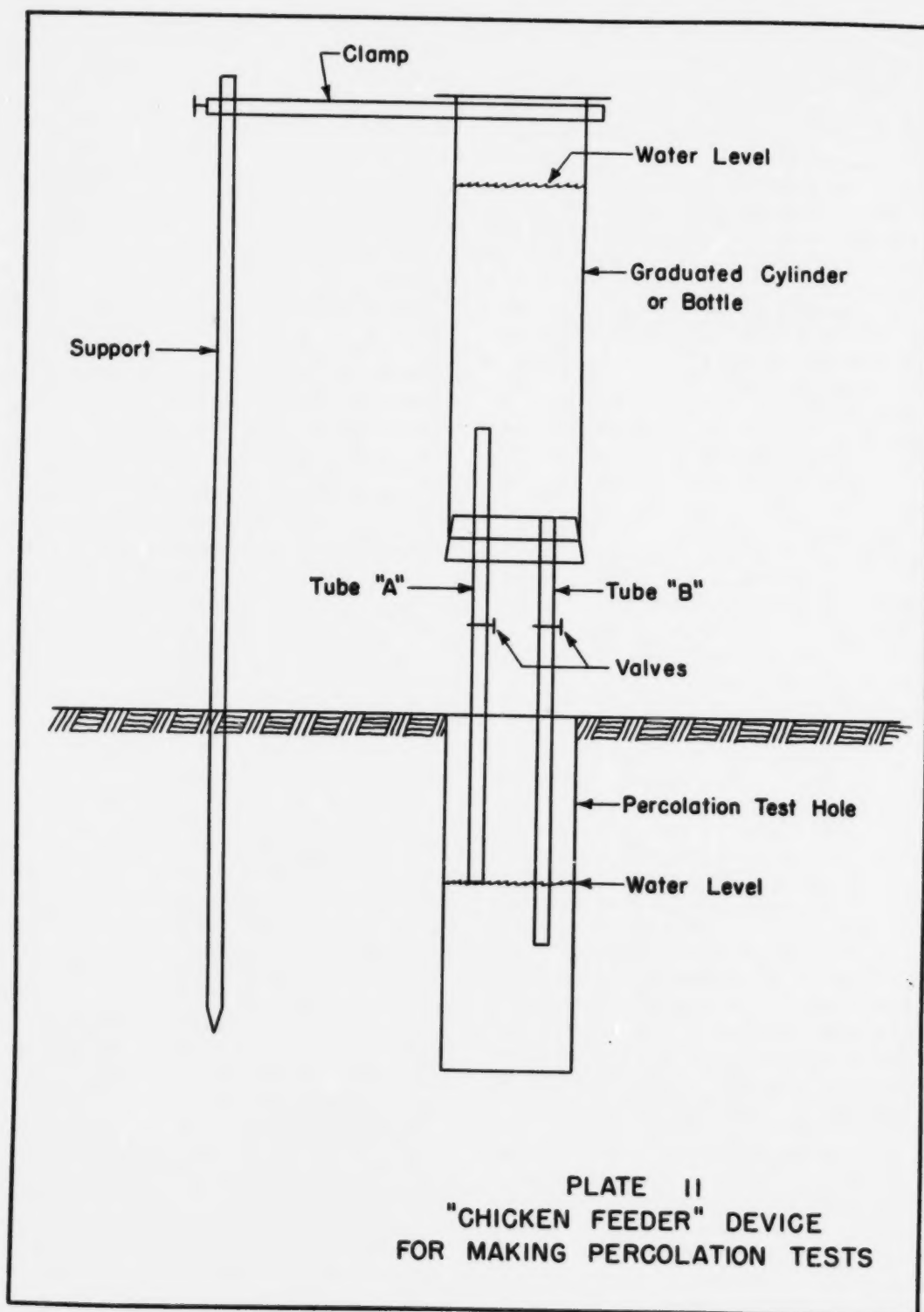
As additional insurance that a representative percolation rate value is obtained, the percolation test measurements should continue over a 2- to 4-hour interval. Measurements of drop in water level should be made at regular intervals of 15 to 30 minutes. Several techniques are available for making routine measurements of the drop in water level. If the rate of fall of the water level is not too fast, the depth to the water level can be measured from the benchmark at the top of the hole by means of a hook gauge. However this technique is rather slow and should only be used on slow soils when more accuracy is desired. A simpler and faster technique is to measure the depth to the water level by use of a rain gauge type of measuring stick. This stick is a thin piece of cedar wood about a half inch wide and 2 feet long, graduated in inches and tenths of inches. It is cheap and readily available from general scientific instrument supply houses. The stick should be placed in the percolation hole to a constant depth for each successive measurement with its end below the water level, quickly removed and the relative water level noted from the water

mark on the stick. The wetted wood dries quickly so that only a few sticks, used in rotation, would be needed for measuring rates on a number of holes simultaneously.

A third type of measuring technique involves the use of a "chicken feeder" type of device shown in plate 11. This equipment consists of a graduated feeder bottle with a water tight lid or stopper into which two lengths of copper tubing are fixed as shown. The equipment can be clamped to a stake or a rod driven into the ground for support. For operation of the percolation test, 6 inches of water is first put in the hole, the feeder bottle is filled, feeding tubes attached, and the device inserted into the hole as shown. Stop cocks or pinch clamps should be provided on the feeder tubes to prevent loss of water during installation into the hole. The valves are then opened and the system allowed to come to equilibrium, that is, when the water level in the test hole comes to the level of the bottom of the air entry tube *A*. A reading of the volume of water in the feeder bottle should be taken at this point. Then as the water level in the test hole drops, the end of tube *A* is uncovered and air enters into the feeder bottle and allows water to feed out through tube *B* into the test hole until the water level in the hole rises and covers the end of tube *A*. The process will continue as long as water remains in the feeder bottle and as long as water is absorbed from the hole. The volume of water percolating out of the hole can be measured at intervals by reading directly the volume of water in the feeder bottle. Knowing the area at the test hole, the percolation rates can be calculated.

The "chicken feeder" technique will maintain a constant water level in the hole within $\pm \frac{1}{8}$ inch, and consequently the percolation rate can be measured with an accuracy of $\pm \frac{1}{8}$ inch during the interval between readings. This degree of accuracy is probably sufficient for soils having rates faster than 1 inch an hour. In slower soils, a more accurate measuring technique should be used.

From the percolation measurements made at intervals, a time curve for the drop in water level can be constructed. Such a curve can be analyzed and the rate most closely approximating equilibrium conditions derived. Such an analysis is illustrated and discussed in the presentation of results.



METHODS

A series of field studies were made in order to compare the standard percolation method to methods based on the suggested modifications.

An area of homogeneous silt loam soil was selected for the studies.

Three different-sized holes, a 12-inch square hole, an 8-inch round auger hole, and a 6-inch round auger hole, were used in the preliminary study. Duplicates of each hole were dug in a 16-square-foot area to a depth of 14 inches. The location of each hole was a random selection on a 2-foot grid system.

One inch of gravel was placed in each hole and 6 inches of water added. The drop in the water level was then measured at intervals over a 3-hour period, refilling the holes as necessary. This initial test will be referred to as the dry run. The holes were then completely filled with water and left to soak overnight. Another series of percolation measurements made in the same manner as the dry run were made the following day over a 3-hour period. This will be referred to as the wet run.

A somewhat more critical study was made later, after a 4-inch auger was obtained. The 4-inch auger allowed a wider range of hole sizes. A 12-inch square hole, an 8-inch round auger hole and a 4-inch round auger hole were used in the second study. A location similar to the location in the preliminary study was chosen. The soil in this area tended to be of a slightly heavier texture. In this second study the holes were replicated three times and two series of runs were made in the same soil area (a 16-square foot area) 2 weeks apart.

RESULTS

The drop in water level in the test holes for all of the individual percolation tests in the 4-, 8-, and 12-inch hole series on the two different dates are shown in plates 12 through 14. The curves emphasize the importance of a critical analysis of percolation test data. Even during the wet runs, when the soil was presumably saturated, there is a considerable change in the rates during the time of the test, a greater

change than could be expected by differences in head. This is apparent from the slope of the curve. All of the curves are steeper at the start of the period than toward the end, that is, the rates start out relatively high and gradually decrease as the test continues, approaching a constant rate. A rate based on the total time of the run would be considerably higher than a rate based on the latter part of the run. For instance, in plate 12 the curve for the wet run in hole No. 2 in the 4-inch group of holes for May 12 and 13 shows a rate of 1.06 in./hr. over the entire period. The rate for the first hour is 2.00 in./hr., for the second hour 0.80 in./hr., and for the third hour 0.55 in./hr. The slower rate toward the end of the run is probably a better index of the absorption rate to be expected under conditions of saturation in a tile field.

Possibly some such mathematical method as discussed by Ludwig and Ludwig (7) can be standardized to determine the equilibrium percolation rate. For the present we will consider the rate over the last 30-minute period of the test as the most representative rate.

The limited data available prohibits an accurate check of the temperature factor, however, the temperature effect in the data reported is probably at a minimum. The water used in all of the tests reported was taken from a small shallow nearby pond whose temperature should closely approximate or parallel air temperatures. The temperatures during May 1949, when the tests were made, were quite uniform and the air temperatures on the days of the tests, over the period of the tests, varied between 70° and 80° F. The rather small variation indicates that the temperature effect was probably rather small, at least compared to variation between replicate tests made during the same period.

In considering the effect of small differences in head on rate measurement, it was assumed, and has been observed, that inherent soil differences between adjacent test holes are greater than those due to small differences in head. In the data reported, the heads in the test holes over the last 30-minute periods of the tests varied from 2 to 6 inches. A comparison of the head to the measured rate over the last 30-minute period showed no correlation.

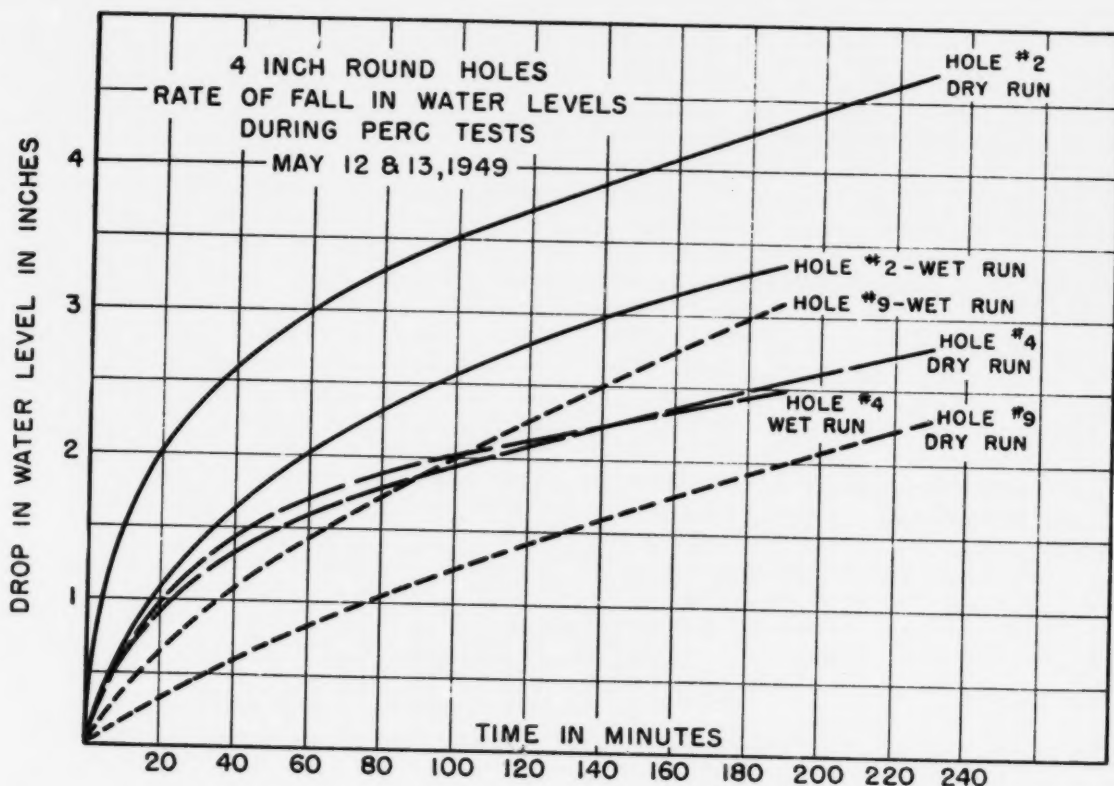


PLATE 12
PERCOLATION TEST STUDIES
RATES OF FALL IN WATER LEVEL

TABLE 19.—Percolation rates* obtained in homogeneous soil in holes of different size and shape

	Size and shape of hole					
	12-inch square		8-inch round		6-inch round	
	Dry run	Wet run	Dry run	Wet run	Dry run	Wet run
	in/hr	in/hr	in/hr	in/hr	in/hr	in/hr
Duplicate No. 1.....	1.500	0.750	2.650	0.950	1.950	1.000
Duplicate No. 2.....	0.900	0.450	1.122	1.060	1.722	0.880
Duplicate average.....	1.200	0.600	1.885	1.005	1.836	0.940
Hole average.....	0.900		1.446		1.388	

* The tabulated rate is the rate over the last 30-minute period of each test.

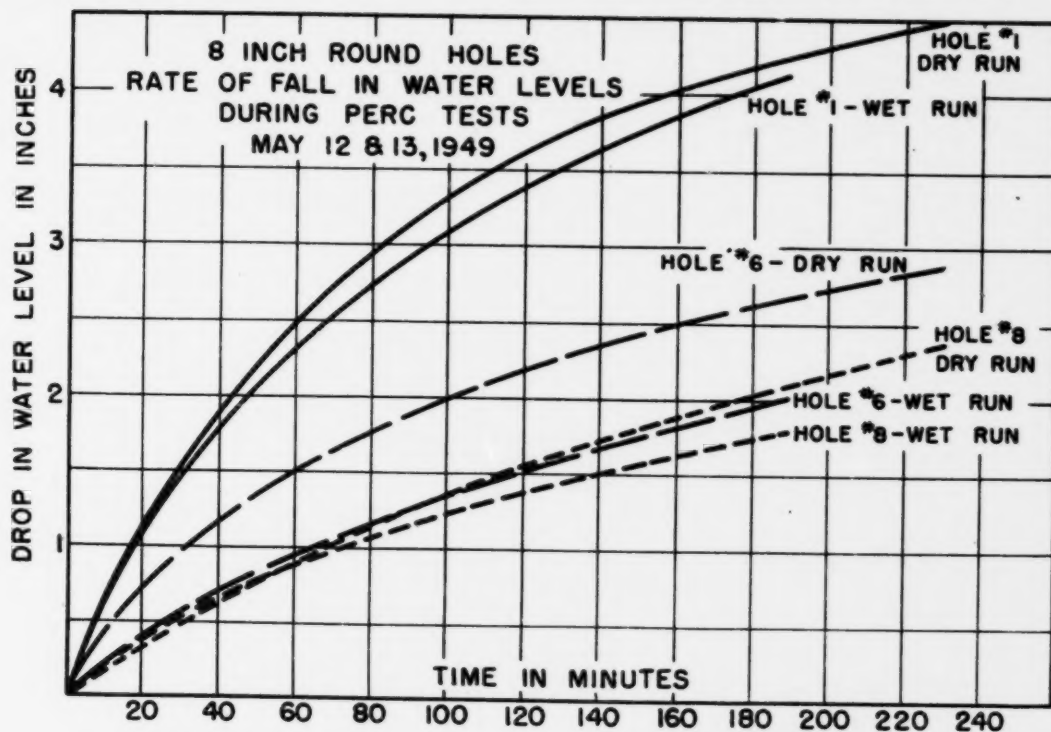
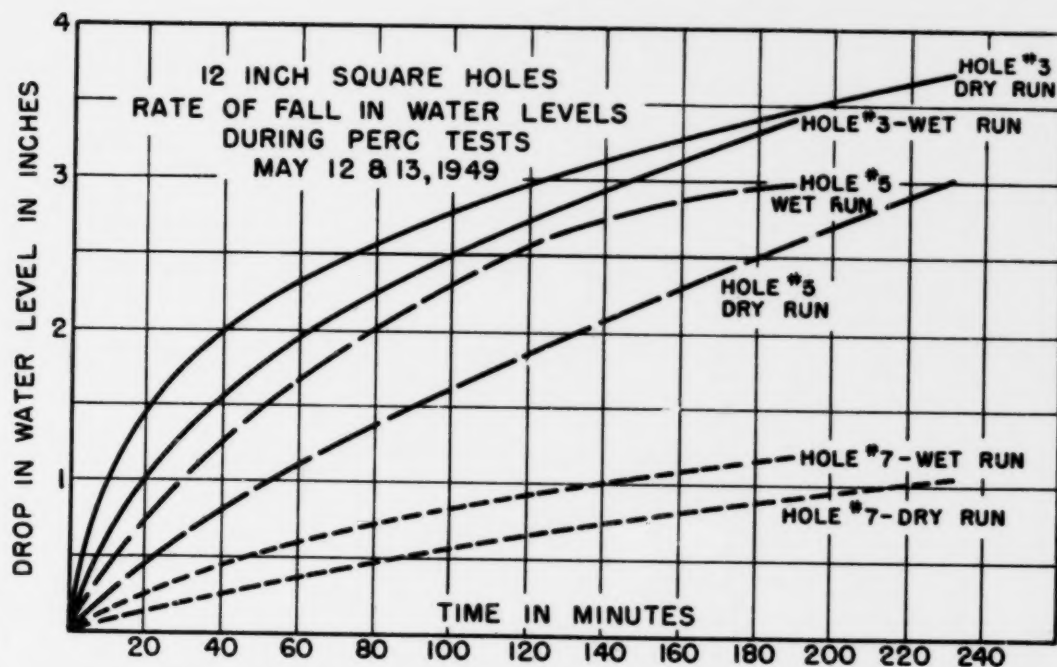


PLATE 13
PERCOLATION TEST STUDIES
RATES OF FALL IN WATER LEVEL

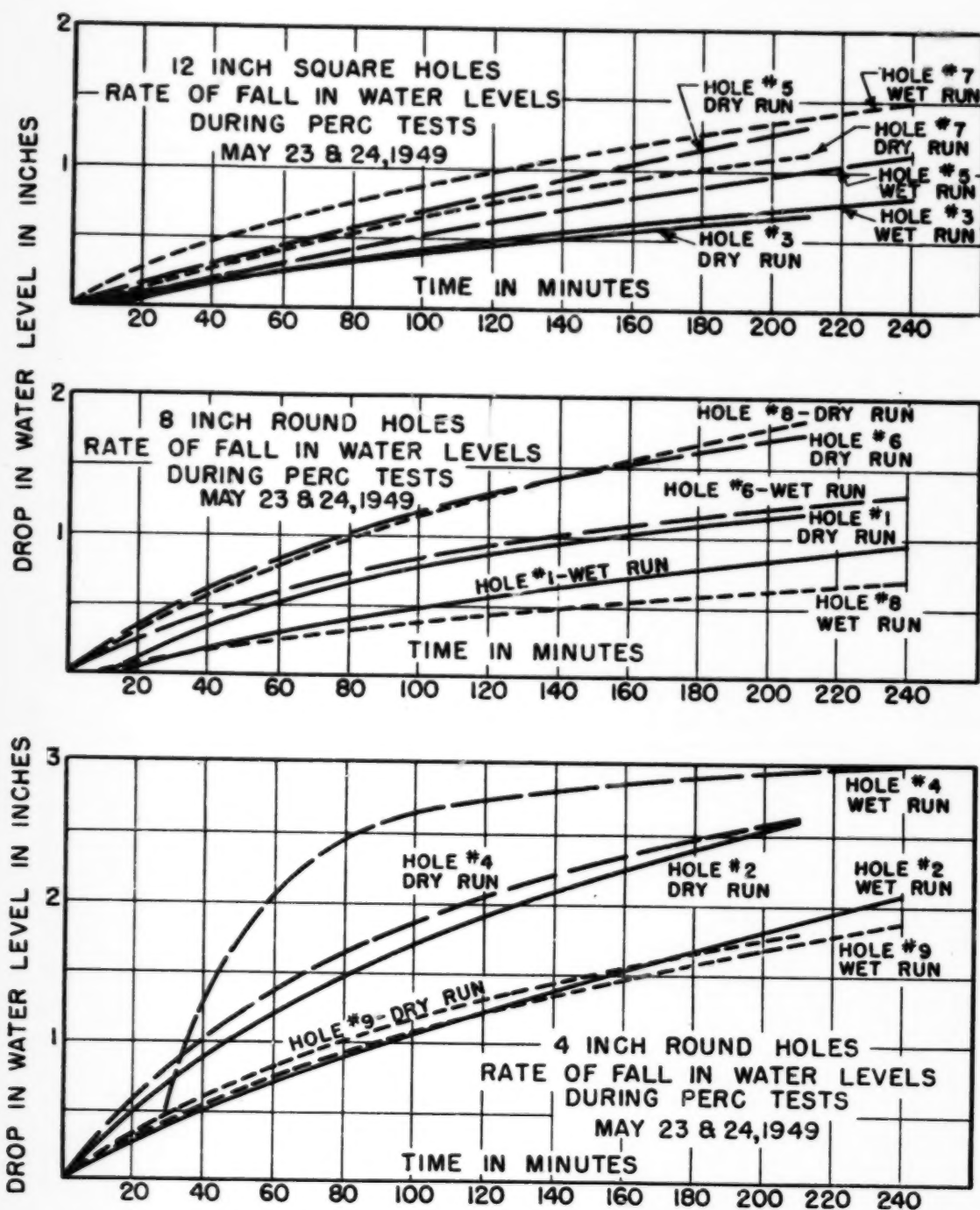


PLATE 14
PERCOLATION TEST STUDIES
RATES OF FALL IN WATER LEVEL

Effect of the Size of Test Hole on Measured Percolation Rates

The results of the preliminary tests on the effect of size of hole on measured percolation rates are tabulated in table 19. The rates given are the rates over the last 30-minute period of each run.

There is no apparent correlation between percolation rates and hole size. Evidently the difference in rates between different sized holes is not a function of hole size. The difference is probably a random difference, since the difference between rates of duplicate holes is as great as, or greater than, the difference between different-sized holes.

In this group of data there does seem to be

a difference between dry run rates and wet run rates, the wet run rates in every case being lower than the dry run rates. The dry run rates were evidently obtained under different conditions of saturation than the wet run rates. However, in a second series of runs on the same soil type there was no significant difference between wet run rates and dry run rates. The magnitude of the rates in the second series of tests was lower than that of the preliminary tests, indicating that the second series was probably made under more saturated conditions.

The results of the second study are shown in table 20. Because of better replication it is possible to inspect these data a little more critically.

TABLE 20.—Percolation rates obtained on different size holes in the same soil on two dates

	Size and shape of hole											
	12-inch square				8-inch round				4-inch round			
	Date 1		Date 2		Date 1		Date 2		Date 1		Date 2	
	Dry run	Wet run	Dry run	Wet run	Dry run	Wet run	Dry run	Wet run	Dry run	Wet run	Dry run	Wet run
	<i>in/hr</i>	<i>in/hr</i>	<i>in/hr</i>	<i>in/hr</i>	<i>in/hr</i>	<i>in/hr</i>	<i>in/hr</i>	<i>in/hr</i>	<i>in/hr</i>	<i>in/hr</i>	<i>in/hr</i>	<i>in/hr</i>
	0.350	0.540	0.140	0.170	0.600	0.450	0.225	0.210	0.425	0.475	0.475	0.450
	.570	.370	.280	.240	.365	.410	.280	.240	.340	.340	.370	.100
	.220	.230	.200	.240	.490	.360	.300	.140	.430	.740	.360	.380
Duplicate avg.:												
By runs.....	.380	.380	.207	.217	.485	.407	.268	.197	.398	.518	.402	.310
Of all dups.....												.347
Run avg.:												
By hole size.....			.293	.298			.376	.302			.400	.414
Of all hole sizes.....											.356	.338
Date avg.:												
By runs.....	0.380		0.212		0.446		0.232		0.458		0.356	
Of all runs.....									0.428		0.267	
Hole avg.....	0.296				0.339				0.407			

* The tabulated rate is the rate over the last 30-minute period of each test.

As mentioned above there appears to be no real difference between the wet run rates and the dry run rates in this group. The average of all wet runs is slightly lower than the average of all dry runs, 0.338 in./hr. compared to 0.356

in./hr. However if we look at the runs on individual holes it can be seen that the wet run rates are higher than the dry run rates about as often as the reverse is true.

The differences in percolation rates between

different-sized holes, dates of tests, and types of run are so small compared to differences between rates obtained on triplicate holes that it was deemed advisable to make a statistical study of the data.

The analysis of variance, which is a statistical tool for comparing the differences or variance between measurements due to controlled factors and due to uncontrolled factors, for the data is shown in table 21. In general, the within-group variance (between replicates)

must be smaller than the between-group (between-treatment) variance in order for real differences to exist between groups.

The only difference in the rates that is significant is the difference between rates on the two separate dates. The variance that is associated with dates is significant at the 5 percent level; that is, the chances are 95 to 5 that this difference is real. The differences due to size of hole and to type of run are not statistically significant.

TABLE 21.—Analysis of variance of percolation rates for different-size holes in the same soil on different dates

Source of variation	Degree of freedom	Sum of squares	Mean square (variance)	Standard deviation
Between hole size.....	2	0.075468	0.037734	
Between dates (within holes).....	3	0.253060	*0.084353	0.106
Between runs (within dates).....	6	0.051262	0.008543	
Between samples.....	24	Pooled 0.349583	0.013362	0.115
Total.....	35	0.729373		

* Significant at the 5 percent level.

SUMMARY

1. Four suggested modifications of the percolation test are made.

(a) Use a 4-inch auger hole in which to make the test instead of the 12-inch-square dug hole.

(b) Obtain a reasonable number of replicate tests in any tile field under consideration and use the average rate as the best estimate of soil absorption characteristics.

(c) Fill the test holes with water and allow the soil to soak overnight before making the percolation test.

(d) In analyzing the percolation test data consider the later period of the test as being more representative of the true absorption rate of the soil.

2. A limited study to compare methods based on suggested modifications to the method was made on one soil. The results show the importance of making replicate tests, and the importance of analyzing the data more critically. No significant difference was found between rates obtained with different-sized holes.

3. It is expected that the soaking procedure will be more important in soils containing ap-

preciable amounts of clay. The soil used in this study was of a silty texture.

4. The basis of the suggestions made is being further investigated in a continuation of field work on a variety of soils.

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SECTION D

Examination of Field Survey Data— Absorption Systems

INTRODUCTION

Field inspections of 300 home septic-tank installations in 9 areas over the country were made by engineering personnel of this Project during the period February 1947 to July 1948.

It was the intention originally to examine both septic tank and soil absorption system at each installation. However, as the survey progressed it became evident that the much greater time consumed in absorption system examination would seriously limit the number of inspections and the amount of septic tank sludge and scum data obtained for study under various time, loading, and design circumstances. As the value of the soil data being collected, in advance of the development of specific criteria of performance, was not established, it was decided to limit the full tile field examinations to about every fifth installation inspected, and to obtain on the remainder only such tile field data as might be obtained quickly from records and the householder.

The localities in which the inspections were made are listed in table 22 together with their identification numbers. Each installation inspected within a particular area was also given an identification number so that, for example, inspection No. 2—18 in table 24 refers to installation No. 18 in the No. 2 (Kansas City) area.

TABLE 22.—Distribution of installations inspected

Area No.	Locality	Number inspections
1	Dallas Co., Texas (Dallas).....	15
2	Jackson Co., Mo., Wyandotte Co., Kan. (K.C.)	92
3	Cook Co., Ill. (Chicago).....	45
4	St. Joseph Co., Ind. (South Bend).....	34
5	Hamilton Co., Ohio (Cincinnati).....	42
6	Kalamazoo Co., Mich. (Kalamazoo).....	10
7	Warwick Co., Va. (Newport News).....	34
9	Montgomery Co., Ala. (Montgomery)....	19
10	Dade Co., Fla. (Miami).....	9
Total		300

As above mentioned, the complete inspection of both tank and tile field was not made on all of the installations. The distribution of installations for which at least partial data pertinent to the study of soil absorption system characteristics were obtained is shown in table 23. The information tabulated for the individual installations may be found in table 24.

TABLE 23.—Distribution of installations for which absorption system data are available

Area No.	Number installations
1	2
2	29
3	15
4	28
5	19
6	2
7	2
9	—
10	—

PROCEDURES

In the cases where the absorption system examination was made, the data obtained included a layout sketch of the system (probed out on the ground by the inspector), a sketch of the trench section, the installation data, method of operation, horizontal trench area, percolation tests, as later described, soil samples for texture analysis, visual observation of inspection pit circumstances and the past history of the installation.

The percolation tests were made under three different conditions at each tile field where possible: (1) A Joint Committee (or unconfined) percolation test was run in a soil area in the tile field unaffected by the septic tank effluent. (2) A confined percolation test, using a 10-inch diameter cylinder forced 2 inches into the soil being tested, was also run in the unaffected area. (3) A confined test was also made in the bottom of the tile trench, that is in the affected soil area.

TABLE 24.—Tile field data from septic tank system field survey reports

Ref. No.	Age of T.F., years	Soil desc. texture*	Veg. cond. over T.F.	Efficiency of T. F.		Number of persons using system		Num. of bedrooms	Water consumption				T. F. trench dimensions				Percolation rates			Effluent load applied				
				At insp.	Past hist.	Adults	Children		Total	Sum-mer-ized	Win-ter-ized	Aver- age gpd	Daily total gal- lons	Length, ft.	Width, ft.	Area, sq. ft.	Vol. of gravel, cu. ft.	Unconf.	Confined	In T. F. in/hr	Out of T. F. in/hr	Vol. gal./sq. ft./day	Rate in/hr	
1-9	15.0	Heavy clay	Trees	Fair	Good	2	2	2	35.0	34.9	35	117	78	60	0.5	300	300	2.37	0.180	0.480	3.30	0.44	0.745	0.050
1-18	22.0	Heavy clay	Light sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-18	2.0	Light clay loam	Light sod	Poor	Poor	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-20	5.0	Light clay	Heavy sod	Fair	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-29	5.0	Black loam	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-30	5.0	Heavy sod	Heavy sod	Fair	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-31	3.0	Clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-32	0.66	Black loam	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-33	1.5	Black loam	Heavy sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-34	6.0	Clay loam	Heavy sod	Fair	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-36	7.0	Black loam	Heavy sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-37	7.0	Clay with loam	Heavy sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-38	7.0	Black loam	Heavy sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-40	4.0	Red clay	Heavy sod	Poor	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-41	4.0	Black loam	Heavy sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-44	9.0	Light loam	Heavy sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-45	10.0	Light loam	Heavy sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-47	13.0	Black loam	Heavy sod	Fair	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-49	4.0	Black loam	Heavy sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-50	25.0	Light clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-54	2.0	Gray clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-101	4.0	Heavy clay	Sod	Fair	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-102	6.0	Lt. Brn. clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-103	6.0	Lt. Brn. clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-105	6.0	Lt. Brn. clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-127	8.0	Red clay	Very lt. sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-129	8.0	Red clay	Very lt. sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-132	8.0	Red clay	Very lt. sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-133	8.0	Red clay	Very lt. sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
2-134	8.0	Red clay	Very lt. sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-7	8.0	Silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-9	7.0	Silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-10	8.0	Silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-11	8.0	Silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-12	11.0	Silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-13	2.0	Silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-18	4.0	Gravelly silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-19	4.0	Black silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-20	0.76	Black silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-22	1.0	Black silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-23	3.0	Black silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-25	25.0	Black silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-26	3.0	Black silty clay	Sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
3-28	9.0	Clayey silt	Black silty clay	Fair	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
4-4	4.0	Sand and clay	Light sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050
4-5	11.0	Compact sand and clay	Heavy sod	Good	Good	2	2	2	32.0	29.8	30	117	78	60	0.5	300	300	2.90	3.42	4.44	0.748	0.050	0.050	0.050

* Texture as judged by field inspector.

* Approximate as scaled from map.

TABLE 24. Tile field data from septic tank system field survey reports—cont'd

Ref. No.	Age of T.F., years	Soil desc. texture*	Veg. cond. over T.F.	Efficiency of T. F.		Number of persons using system		Num-ber of bed-rooms	Water consumption				T. F. trench dimensions				Percolation rates			Effluent load applied		
				At inap.	Part hist.	Adults	Child		Total	Sum-mer gpd	Win-ter gpd	Aver- age gpd	Daily total gal-	Length, ft.	Width, ft.	Area, sq. ft.	Vol. of gravel, cu. ft.	Unconf. T. F. in/hr	Confined T. F. in/hr	Out of T. F. in/hr	Vol. gal./sq. ft./day	Rate in/hr
4-4	3.0	Sandy, with some clay.	Heavy grass.	Good	Good	4		4		4		156	156	182	1.66	220	440	5.40	0.36	0.33	3.00	
4-7	2.0	Sandy.	Light sod.	Good	Good	4		4		4		156	156			300		6.36	0.24	1.20		
4-8	2.0	Sandy.	Light sod.	Good	Good	4		4		4		156	156			300		6.36	0.24	1.20		
4-9	21.0	Sandy.	Sod.	Good	Good	4		4		4		156	156			300		2.25	4.08	8.62	2.28	
4-10	6.0	Sand and loam.	Sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-13	4.0	Sand and loam.	Sod.	Good	Good	4		4		4		117	117			308	462	4.32	4.80	7.20		
4-14	4.0	Sand and loam.	Sod.	Good	Good	4		4		4		117	117			308	462	4.32	4.80	7.20		
4-15	4.0	Sand and loam.	Sod.	Good	Good	4		4		4		117	117			308	462	4.32	4.80	7.20		
4-16	12.0	Sand and loam.	Sod.	Good	Good	4		4		4		117	117			308	462	4.32	4.80	7.20		
4-17	17.0	Sand and loam.	Sod.	Good	Good	4		4		4		117	117			308	462	4.32	4.80	7.20		
4-18	4.0	Sand and loam.	Sod.	Good	Good	4		4		4		117	117			308	462	4.32	4.80	7.20		
4-19	4.66	Sand and loam.	Sod.	Good	Good	4		4		4		117	117			308	462	4.32	4.80	7.20		
4-20	7.0	Sand and loam.	Sod.	Good	Good	4		4		4		117	117			308	462	4.32	4.80	7.20		
4-21	4.0	Sand and loam.	Sod.	Good	Good	4		4		4		117	117			308	462	4.32	4.80	7.20		
4-22	8.0	Sand and clay.	Heavy grass.	Good	Good	4		4		4		156	156	182	1.66	220	440	5.40	0.36	0.33	3.00	
4-23	6.0	Sandy.	Light sod.	Good	Good	4		4		4		156	156			300		6.36	0.24	1.20		
4-24	8.0	Sandy.	Light sod.	Good	Good	4		4		4		156	156			300		2.25	4.08	8.62	2.28	
4-25	9.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-26	1.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-27	1.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-28	1.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-29	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-30	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-31	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-32	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-33	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-34	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-35	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-36	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-37	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-38	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-39	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-40	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-41	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-42	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-43	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-44	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-45	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-46	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-47	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-48	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-49	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-50	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-51	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-52	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-53	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-54	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-55	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-56	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-57	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-58	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-59	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-60	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-61	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-62	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-63	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-64	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-65	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-66	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-67	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-68	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-69	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-70	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-71	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-72	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-73	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-74	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-75	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-76	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-77	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-78	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-79	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-80	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-81	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.80	7.20	
4-82	2.0	Sand and clay.	Light sod.	Good	Good	4		4		4		156	156			300		4.08	8.62	4.8		

* Texture as judged by field inspector
 * Approximate as scaled from map.

The percolation data were analyzed and the percolation rate for each test calculated by the method described elsewhere in the report. Briefly, the method is to plot the fall in water level in the test hole in inches against time and then fit a smooth curve through the data. The last 30-minute section of the curve is considered the most representative of the equilibrium rate, and the rates presented here are calculated from this section.

The per capita water consumption at each household where septic tank systems were inspected was determined from 3-month summer and winter water meter records obtained at the time of the survey. The tile line trench area was measured or estimated in the field. From the above information, the effluent load applied to each tile field has been calculated. The loads applied are tabulated in gallons of effluent per square foot of trench area per day, and also in inches of effluent per hour.

Consideration should be given in future work to the reporting of percolation rates in inches per hour, rather than minutes per inch. The inches per hour terminology is the more standard usage, and the more logical. Rate measurements in general are measured and reported on a basis of units per time, i. e., gallons per hour, cubic feet per second, inches per hour, etc.

The performance of each individual tile field is based on past history and observations at the time of the inspection. The efficiencies have been divided into three categories: (1) Good—tile field has never given any trouble; (2) Fair—seepage to the ground surface has been observed occasionally; (3) Poor—the tile field has given trouble continuously.

The value of soils data obtained during the survey is limited by several considerations, among them that only a single percolation test of each type was made at each tile field. An estimate of the tile field soil absorption characteristics based on this single measurement is open to question. The necessity for a replication of tests, due to the inherent variability of soils as well as the variability associated with the operation of the test, in order to obtain a fair estimate of soil absorption characteristics, is discussed in the section on percolation test studies. However, despite the inadequacy of the data several comparisons can be made in order to show trends.

RESULTS

Three general comparisons that may give needed soils information have been made: (a) a comparison of unconfined percolation test rates, measured in unaffected areas of the tile field, to the actual effluent loading rate on the tile field; (b) a comparison of confined rates measured in unaffected soil to confined rates measured in affected soil of the tile field; and (c) a comparison of unconfined percolation tests to confined percolation tests, both made in the unaffected area in each field, and in close proximity to each other.

(A) Unconfined Percolation Test Rates vs. Effluent Loading Rates. A comparison of the soil percolation rates of fields as measured by the Joint Committee (unconfined) method to the actual effluent loading rates on the tile fields affords an opportunity to compare the original Ryon study with a similar study involving different soils. The data from 45 systems where the tile field history, the unconfined percolation rates in unaffected soil, and the tile field loading rates are available, are tabulated in table 25. The data included in this group probably represent a different range of soils and soil conditions than the Ryon (1) data. The Ryon study was presumably made on systems in New York State. The data in table 25 are from systems in four widely separated areas; 24 systems in the Kansas City area; 7 systems in the Cook County, Ill., area; 12 systems in the Cincinnati, Ohio, area; and 2 systems in the Newport News, Va., area.

The ages of the systems vary from 1 year to 18 years. Sixty-six percent of the systems are 5 years or older and 62 percent are from 5 to 10 years old. The average age of all the systems is about 5½ years.

The loading rates and the percolation rates of the 45 systems are plotted in plate 15 on a reproduction of the original Ryon curve and data. The tile field efficiencies are shown by an appropriate symbol.

The survey data give a wider range and more uniform distribution of points along the curve than the original Ryon data, particularly on the percolation rate axis.

The percolation rates of the original Ryon data may not be directly comparable to the sur-

vey percolation rates. The Ryon rates may tend to be somewhat faster for similar soils than the survey data, as they are presumably based on a steeper part of the percolation curve than the survey data. This would tend to shift the survey points to the left relative to the Ryon points for a direct comparison. However, within the range of the data presented here this would not alter the over-all relationship between the Ryon data and the survey data.

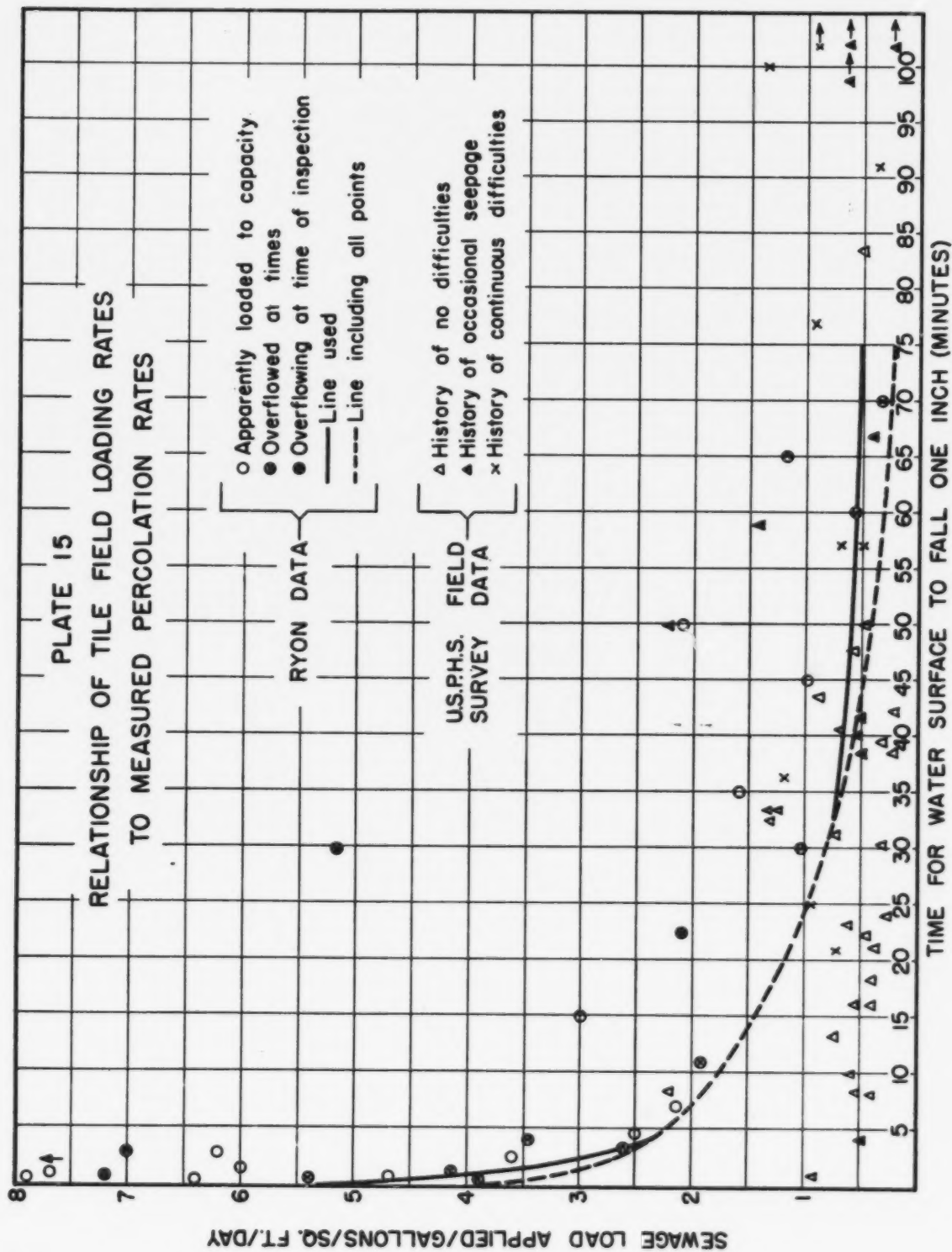
The Ryon curve, enveloping systems either

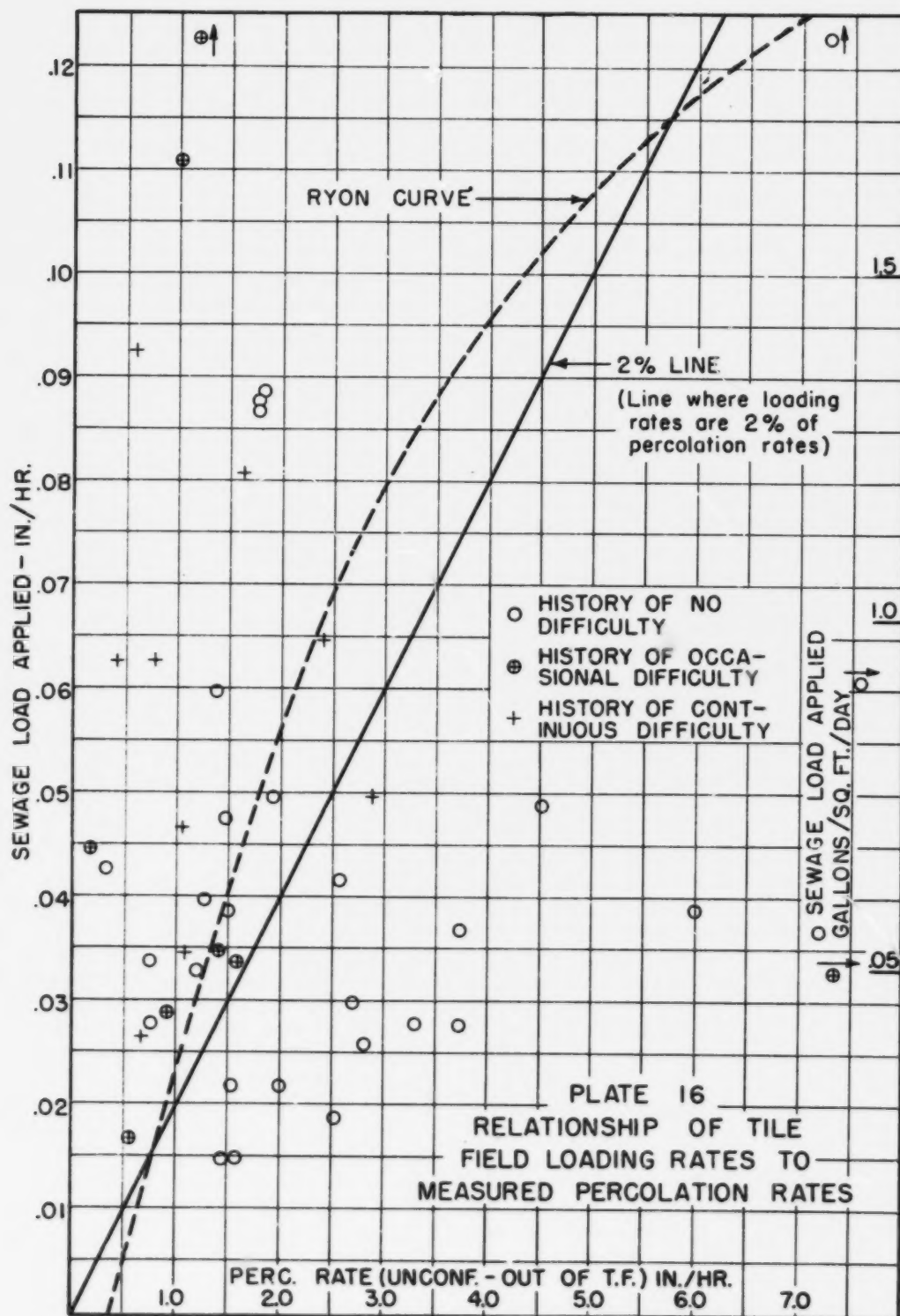
loaded to capacity or overflowing, seems to fit the Public Health Service survey data fairly well. Of 9 systems having a history of continuous trouble only 1 falls any distance outside of the enveloping curve, the other 8 systems falling on or well within the curve. Of 9 other systems with histories of occasional seepage only 1 falls any distance outside of the enveloping curve. Of 27 systems having a history of no difficulties, 22 fell on or outside this curve and 5 inside, also bearing out the fit.

TABLE. 25—Comparison of tile field efficiency percolation rate, and loading rate

Ref. No.	Age, years	Efficiency ¹	Percolation rate		Loading rate	
			In/hr	Min/in	In/hr	Gal/sq.ft./day
2-18	2	P	2.88	20.8	0.050	0.748
2-20	5	F	14.40	4.2	0.033	0.490
2-26	6	P	0.43	139.4	0.063	0.940
2-29	5	G	2.84	21.1	0.026	0.386
2-30	5	F	1.56	38.4	0.034	0.514
2-31	3	P	0.60	100.0	0.093	1.400
2-37	5	F	0.54	111.0	0.017	0.254
2-39	7	G	2.58	23.2	0.042	0.627
2-41	4	P	0.78	77.0	0.063	0.952
2-43	4	G	4.50	13.3	0.049	0.732
2-44	9	G	1.80	33.3	0.087	1.300
2-45	10	G	7.26	8.3	0.148	2.200
2-47	13	F	1.20	50.0	0.150	2.258
2-49	6	G	3.72	16.1	0.037	0.559
2-50	18	G	1.92	31.2	0.050	0.750
2-54	2.5	G	1.26	47.6	0.040	0.600
2-101	4	F	1.02	58.8	0.113	1.700
2-102	6	P	0.66	91.0	0.027	0.405
2-103	6	G	3.72	16.1	0.028	0.419
2-105	5	G	1.20	50.0	0.033	0.490
2-127	3	G	63.00	0.95	0.061	0.924
2-129	6	G	3.30	18.2	0.028	0.418
2-133	3	G	1.42	42.2	0.015	0.225
2-134	6	G	1.52	39.4	0.022	0.330
3-19	4	G	1.38	43.5	0.060	0.910
3-20	0.8	G	1.80	33.3	0.088	1.320
3-22	1	G	7.20	8.3	0.037	0.557
3-25	7	G	1.56	38.4	0.015	0.223
3-26	6	F	1.44	41.6	0.035	0.531
3-28	5	F	0.90	66.7	0.029	0.430
3-41	9	G	6.00	10.0	0.039	0.590
5-1	6	P	2.40	25.0	0.065	0.965
5-2	6	G	1.50	40.0	0.039	0.578
5-3	6	G	1.85	32.4	0.089	1.330
5-4	6	P	1.65	36.3	0.081	1.220
5-5	6	P	1.05	57.1	0.035	0.518
5-6	6	P	1.05	57.1	0.047	0.711
5-7	1	G	2.70	22.2	0.030	0.453
5-13	3	F	0.75	80.0	0.028	0.412
5-14	3	F	0.15	400.0	0.045	0.668
5-23	5	G	1.98	30.3	0.022	0.326
5-39	0.5	F	0.31	193.4	0.043	0.650
5-40	9	G	1.48	40.5	0.048	0.713
7-5	9.5	G	0.72	83.4	0.034	0.512
7-10	8.5	G	2.52	23.8	0.019	0.278

¹ Based on past history and observations at time of inspection.
G = good; F = fair; P = poor.





A number of the systems with histories of difficulties fall beyond the range of the Ryon curve, that is, they have percolation rates greater than 75 minutes per inch. In order to see the relationship of these systems to the general curve the data have been replotted in plate 16.

The loading and percolation data are presented in a more conventional manner in plate 16. The loading rates are plotted in inches per hour (and an equivalent scale in gallons per square foot per day) and the percolation rates are plotted in the more conventional inches per hour. The relative position of the Ryon curve is shown. The same relative relation between the survey system efficiencies and the Ryon curve is of course maintained, but the direct relationship between the loading rates and the percolation rates may be more understandable.

On the basis of the survey data, the Ryon curve appears to give a fair estimate of permissible tile field loading rates when derived from unconfined percolation rates. Very few of the points representing survey systems are contradictory to the Ryon curve.

In plate 16 a line representing loading rates which are 2 percent of the measured percolation rates has been drawn in. The line falls quite close to and envelopes the nonworking tile fields about as well as the Ryon curve for percolation rates up to 6 inches per hour. It might be said then that for the particular systems studied a fair estimate of permissible load rates can be obtained by decreasing the measured percolation rates by 98 percent. This reduction in absorption rates is due to several factors but is probably primarily a function of the soil clogging from effluent treatment. The 98 percent reduction indicated here agrees quite well with the amount of clogging measured in the soil core experiments. The soil core data presented and discussed elsewhere in the report indicate at least an 80 percent reduction in percolation rates due to soil clogging when treated with sewage effluent.

(B) Confined Percolation Rates Out of Tile Field vs. Confined Percolation Rates in the Tile Field. A comparison of confined percolation rates measured in unaffected soil areas in the tile field to confined percolation rates measured in affected soil areas, that is, in the bottom of

the tile trench, has been made in an attempt to get additional information on soil clogging.

Data are available from 25 of the systems inspected during the survey. These data are tabulated in table 26. The ages of the systems vary from 1 to 22 years. Seventeen of the systems are 5 years or more old. The average age of the systems is about 6½ years. The rate data are plotted against each other in plate 17.

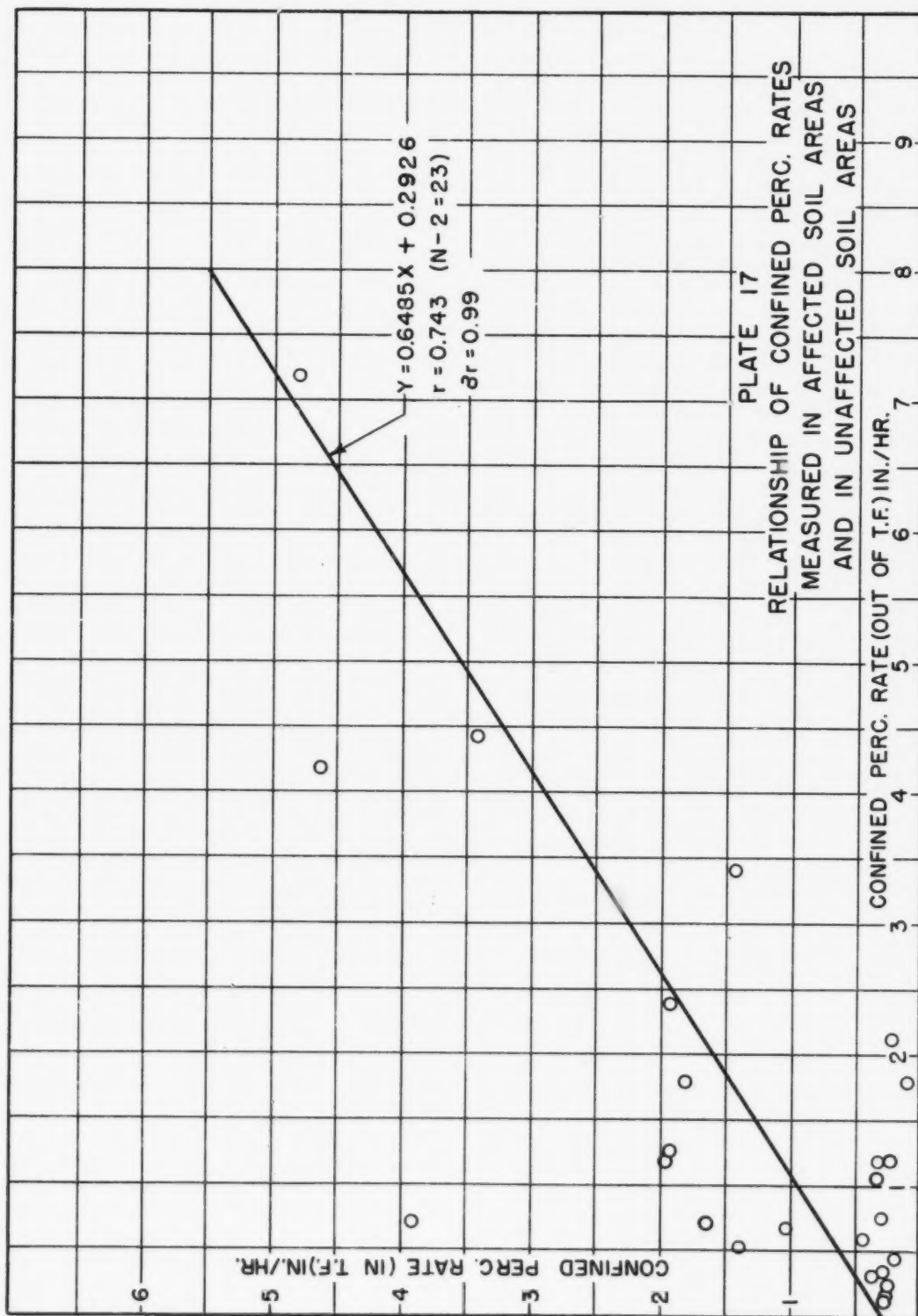
TABLE 26.—Confined percolation rates made in tile field and out of tile field

Ref. No.	Age, years	Efficiency	Confined percolation rate	
			In T. F., in/hr	Out of T. F., in/hr
1-9-----	15	F	0.18	0.48
1-18-----	22	G	3.42	4.44
2-40-----	1	G	1.92	1.26
2-43-----	4	G	1.95	1.20
2-47-----	13	F	0.20	2.13
2-134-----	6	G	0.24	0.18
3-7-----	8	P	0.30	1.20
3-13-----	2.5	G	4.62	4.20
3-19-----	4	G	1.92	2.40
3-28-----	5	F	1.38	0.54
4-4-----	11	G	3.90	0.72
4-5-----	6	G	1.80	1.80
4-7-----	2	G	0.36	0.33
4-8-----	2	G	0.24	1.20
4-13-----	6	G	4.80	7.20
5-2-----	6	G	1.65	0.72
5-3-----	6	G	0.28	0.76
5-4-----	6	P	0.26	0.36
5-5-----	6	P	0.08	1.80
5-6-----	6	P	0.32	1.05
5-14-----	3	F	0.24	0.26
5-39-----	1	F	0.25	0.15
5-40-----	9	G	0.42	0.60
7-5-----	10	G	1.02	0.69
7-10-----	8	G	1.42	3.42

The plotted data tend to follow a linear correlation, the calculated correlation coefficient being 0.743, which is statistically significant.

However, there appears to be a wide variability or scattering of the plotted data. The mean of the rates measured in affected soil areas is 1.59 inches per hour. The standard deviation of the scatter about the regression line, of the affected soil rates is 0.99 inches per hour. This rather large variability of affected soil rates limits the practical usefulness of the line for estimating values of confined rates in affected soil areas from measured rates in unaffected soil areas.

The wide variability or scatter of the data is



probably due to a number of factors. In the first place, the data include systems of different ages and, as the relationship between percolation rates of unaffected and affected soils is undoubtedly a function of the age of the tile field, some scatter of data about the regression line can be expected from this source. Secondly, the data represent a variety of soil types varying in structure characteristics as well as texture. The relationship, again, between percolation rates of unaffected soil and affected soil is probably a function of the type of soil. The change in the percolation rate of a sandy soil after being treated with septic tank effluent is probably different than the change in the rate of a clay soil. Therefore additional variability or scatter of the plotted data can be expected from this source. Further variability of the data might be expected from differences in the rate of applying effluent, differences in the distribution of effluent in the tile field and differences in disposal trench widths and areas.

If sufficient data were available it might be grouped according to age of the tile system, type of soil, etc., and a practical relationship between the percolation rates of unaffected soil and of affected soil might be derived. The present data are too meager to allow this type of grouping and comparison.

The over-all relationship of the present data shows the general trend. The percolation rates measured in affected soil areas tend to be less than the rates measured in unaffected soil areas. In order to interpret this difference, as a quantitative measure of soil clogging, additional data are needed.

The accumulation of this type of data during any studies of operating tile fields which may be undertaken will be continued. Future data will be taken under more carefully controlled conditions, i. e., replication of tests, better approximation of saturation, grouping of soils, grouping of systems as to age, etc. It is hoped that a more critical analysis can then be made and a better estimate of soil clogging arrived at.

(C) Unconfined vs. Confined Percolation Rates. A comparison of the unconfined percolation rates and the confined percolation rates made under the same soil conditions has been made in an attempt to develop a factor to con-

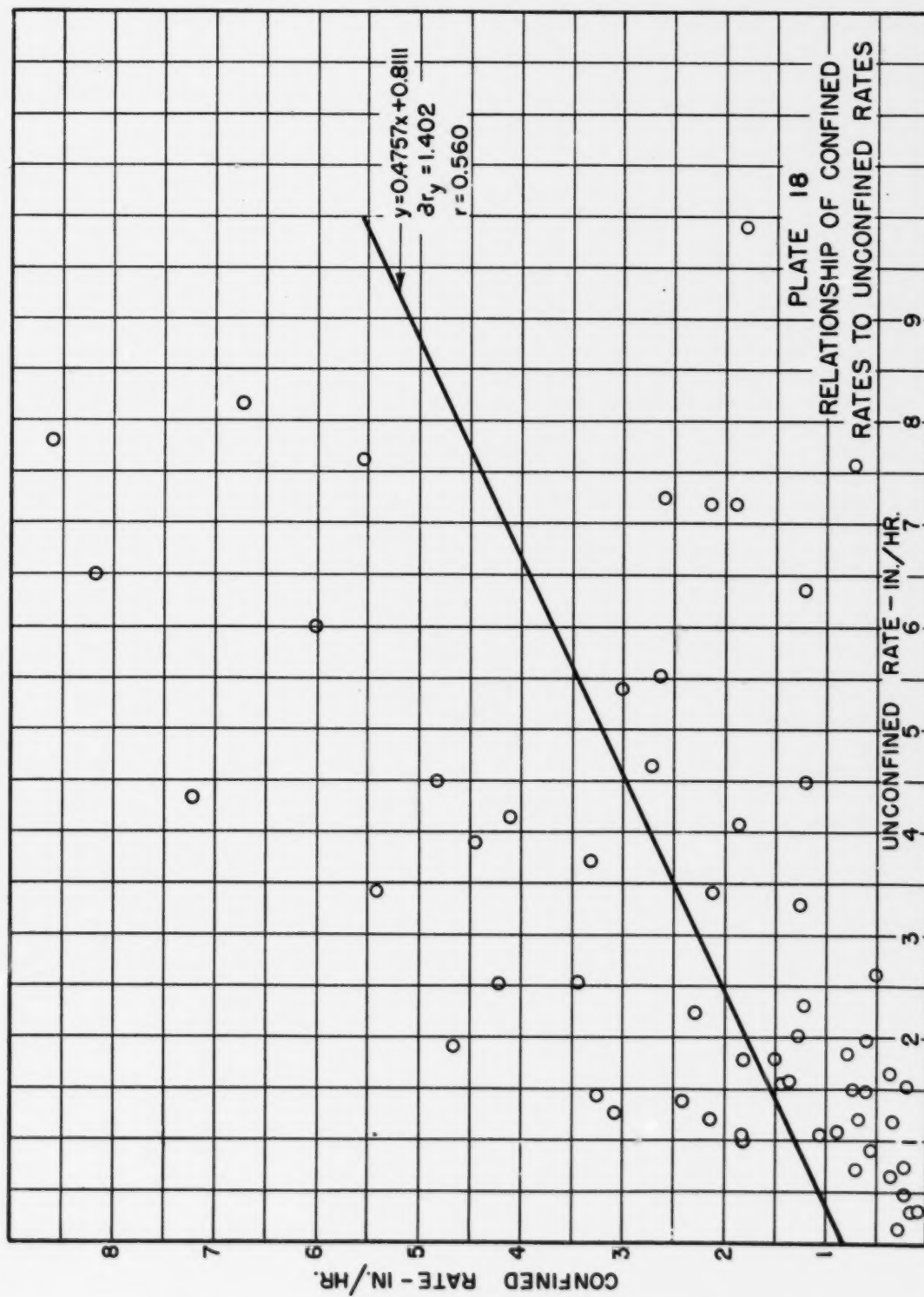
vert from one type of measurement to the other. It is desirable to be able to convert from one type of rate to the other in making soil clogging studies. Measurement of percolation rates in clogged soil (the bottom of the tile trench) can only be made by the confined test method. Measurement of rates in unaffected soil is typically made, because it is relatively simpler, by the unconfined or Joint Committee method. In order to get a measure of the clogging that has taken place it is necessary to compare the rates on a common base. The relationship of the two methods therefore, must be known so that the rates can be converted to comparable values.

Data from 59 systems were used in the comparison of confined and unconfined percolation rates. Only the systems having percolation rates of 10 inches per hour and less were used, as the rates greater than this were obviously erratic. The data are plotted in plate 18.

Considering the data as a whole, there is a significant linear correlation, the correlation coefficient being 0.560. However, here again, as in the comparison of affected soil *vs.* unaffected soil rates discussed above there is a wide scatter of the plotted data, which limits the practical usefulness of the regression line.

The mean of all the confined percolation rates is 2.30 inches per hour. The standard deviation of the scatter of the confined percolation rates about the regression line is 1.40. The equivalent 95 percent confidence limit is 2.80; that is, for a given unconfined percolation rate, the best estimate of the corresponding confined rate that we can make, with 95 percent confidence, is the value taken from the regression line plus or minus 2.80 inches per hour. For instance, for an unconfined percolation rate of 5 inches per hour, we can only estimate that the corresponding confined rate should be between 0.4 and 6.0 inches per hour. Such a wide variation greatly limits the practical usefulness of the regression line.

The regression line is the line from which the best estimate of a confined rate can be obtained for a given value of an unconfined rate. However, the regression line for this data does not appear to bear out a logical relationship between the two types of rates. For a given unconfined rate of 1.5 inches per hour or less, the estimated confined rate obtained from the re-



gression line will be greater than the unconfined rate. Such a relationship does not seem logical, as conditions of running the two tests favor a lower confined rate. The unconfined method offers a larger soil area through which percolation can take place while all other conditions are kept the same.

At rates greater than 1.5 inches per hour the regression line will give an estimated confined rate less than the unconfined rate which is logical.

It must be remembered that in this case, as in the case of the unaffected soil rates *vs.* the affected soil rates, that the data analyzed represent a wide variety of soils. Consequently the regression line merely shows an average relationship. It is quite probable that the relationship between confined and unconfined rates is specific to particular soils or groups of soils. Sandy soils may have one relationship and clay soils another and quite different relationship. Sandy soils, where percolation downward is quite fast and capillary flow laterally is at a minimum, will probably have a smaller difference between confined and unconfined rates than would a clay soil where percolation downward is slower but the chances for capillary flow laterally may be greater. Therefore, the position and shape of a regression line for sandy soils will probably be different from one for clay soils.

The present data are considered inadequate to establish a practical relationship between unconfined and confined percolation rates, but in future work it is hoped that more critical data will enable a practical relationship to be developed.

SUMMARY

1. Pertinent soils information from the septic tank systems inspected by field crews have been tabulated.

2. A comparison of sewage effluent loading rates applied to these systems with the percolation test rates in the unaffected soil tends to agree with the original Ryon study. From this comparison it also appears that for the group of systems examined, the borderline between successful and unsuccessful operation fell at sewage loading rates approximating 2 percent of the unaffected soil percolation rates.

3. A comparison of percolation rates measured in affected soil areas with percolation rates measured in unaffected soil areas shows a significant correlation in a trend toward reduced rates in the affected soils. However, additional data are needed to develop this relationship for practical use in estimating the magnitude of the reduction in rate.

4. A comparison of percolation rates measured by the unconfined method to rates measured by the confined method also shows a significant correlation. Due to the wide variability in the data additional data are needed here also before a practical relationship can be established.

REFERENCE

- (1) Federick, J. C., "Solving Disposal Problems in Unsewered Areas." *Sewage Works Engineering*, vol. 19: p.292-294, June, 1948.

SECTION E

Permeability Conditions in Operating Tile Fields

INTRODUCTION

A planned detailed soil study of tile fields in operation under actual household conditions has been started. The study is planned to provide basic information on soil absorption characteristics, soil moisture distribution, and soil moisture movement within a tile field. The study should also provide information on soil changes that occur under septic tank tile field conditions.

Through the cooperation of Mr. E. L. Hess, a septic tank cleaner in the Cincinnati area, a number of septic tank systems have been inspected for possible use in the study. A study of one system has been completed.

System Selected for Study

The tile field selected for the first study is located near Bevis, Ohio, about 12 miles northwest of Cincinnati. The owner, Mr. Carl Lit-schi, was very cooperative in giving permission for unlimited inspection of the tile field area.

This septic tank system has been in operation for about 6 years, being used by two adults and two children during the major part of the period. The water supply is from a cistern and from a dug well. The tank, a 500-gallon capacity rectangular tank, has been cleaned twice in the 6 year period, once after the first 4 years of operation and again after an additional 2 years of operation.

The tile line system is 250 feet long, consisting of two lines 100 feet long and one line 50 feet long spaced 6 feet apart. The tile trench is 18 inches wide, filled with 1 foot of pea gravel, 6 inches below the tile and 2 inches above. The tile is 4-inch drain tile.

According to the owner the tile field has never given any trouble.

Soils Description

The tile field is in a soil area that appears to have relatively poor absorption characteristics.

As an absorbing system the field can probably be separated into two sections. The section of the tile field nearest the septic tank (lawn area) is in relatively more shallow and less permeable soil than the outer end of the tile field. In the lawn area the soil in the 0- to 12-inch depth is a yellow silty clay with a rather weak fragmental structure. The 12- to 30-inch depth is a mottled red and yellow clay grading into a grayish plastic clay at 27 inches. The bottom of the tile trench in this area is at 27 inches. The area has a grass and clover lawn cover. There are a few fine roots throughout the soil to the 27-inch depth.

The outer half of the tile field is in an old chicken yard that has a heavy annual growth of milk weed. The soil in this area is a little deeper and appears to have better absorption characteristics. The 0- to 14-inch depth has been plowed and mixed in the past. It grades from a brown silt loam at the surface to a yellowish brown silty clay at 14 inches. There is a good crumb structure and considerable evidence of root holes, worm holes, and solution channels through this depth. The 14- to 30-inch depth grades from a yellow clay loam with strong fragmental structure to somewhat heavier clay at 30 inches. The same mottled and plastic clay layer found in the lawn area at about 24 inches is not encountered here until the 36- to 42-inch depth. There is considerable evidence of solution channels and relatively large cracks between soil structural units, and many large roots above the 30-inch depth. Evidence of earthworm activity was found as deep as 24 inches. The tile trench in this area is at the 24-inch depth.

Surface drainage from the entire area is good. The field is on approximately a 3 percent slope with a southern exposure.

Experimental Methods

A trench 18 inches wide and 10 feet long was cut across one of the tile lines down to the top of the gravel in the tile trench. The gravel and

one section of tile were removed from the tile trench. A 10-inch-diameter, steel cylinder was forced 2 inches into the bottom of the tile trench. At distances of 2 feet and 4 feet on either side of the tile trench, 1-foot-square holes were excavated in the cross section trench to the depth of the bottom of the tile trench. At a distance of 2 feet on each side of the cross section trench, auger holes of two different sizes were bored to the same depth and in the same relative cross section location as the square holes. Percolation tests were then run in all of the test holes at the same time. The tests were made over a 2-day period. The first day's test will be referred to as a dry run and the second day's test as a wet run. The amount of percolation taking place overnight was also measured where possible.

When the hole percolation tests were completed, undisturbed core samples were taken from the bottom of each percolation hole with a drive-type sampler. Core percolation rates and macro-pore space volumes were obtained on the undisturbed samples in the laboratory.

In the lawn area only three percolation tests were made, one in the tile trench and one at a distance of 2 feet on each side of the tile trench.

The more detailed studies were made in the chicken yard area of the tile field.

A few core samples were taken horizontally in order to compare the relative rate of water movement laterally to vertically.

Results

Some interesting observations of unmeasurable conditions in the tile field are of interest. In both locations where the tile trench was opened, the root distribution was striking. There was a considerable accumulation of roots in the gravel below the tile line and practically none above. The majority of the roots were concentrated in a mat in the 2 inches of gravel below the tile. No evidence of roots in the tile was seen.

The soil in the bottom of the trench showed some accumulation of sludge and was discolored to a depth of about 3 inches. The discoloration of the soil in the outer part of the field was to a greater depth than that closer to the tank, indicating that the outer part of the field received a larger part of the effluent.

TABLE 27.—Permeability conditions in an operating tile field

Hole number	Lawn area			Chicken yard area					
				East cross-section		Center cross-section			
	1	2	3	6	7	8	1	2	3
Hole location	2' north of tile	In tile trench	2' south of tile	4' north of tile	2' south of tile	4' south of tile	4' north of tile	2' north of tile	In tile trench
Hole size	12" square	10" round confined	12" square	8" round	6" round	6" round	12" square	12" square	10" round confined
Hole perc. rate—dry run*	0.062		0.062	0.900	0.075	0.210	0.375	0.065	
Hole perc. rate—wet run				0.525	0.075	0.100	0.447	0.180	
Confined perc. rate		0.015					0.270		
Average of all hole rates				0.0645		0.0688	(0.151)	(0.122)	(0.000)
Core perc. rate—vert.	0.0054	0.0064	0.0062	0.0065			(0.051)	(0.042)	(0.0034)
Average of all core rates							(0.0058)	(0.0042)	(0.0034)
Core perc. rate—horiz.							(0.0055)		
Pore space—vert.*	2.8	2.8	4.0	2.8		2.0	2.2	1.8	2.2
Average of all pore spaces							(2.2)	(1.8)	(2.2)
Pore space—horiz.							2.6	2.6	2.6
							(2.4)	(2.4)	(2.4)
							0.670	0.810	0.030
									0.136
									0.150
									0.038
									0.0098
									0.0086
									0.0022
									0.0112
									2.6
									2.3
									(2.2)
									3.2

* Perc. rates reported as inch/hour.

** Pore space reported as % volume of soil that is macro pore space.

Considerable lateral movement of water through the soil was noted when the percolation holes were first excavated. In some cases lateral movement of water into the holes prevented their being used in making percolation tests. This was particularly true in the holes closest to the tile lines.

The basic data obtained in the studies is shown in table 27. Although the amount of data is limited, it does show some trends.

The percolation rates made in holes 2 feet from the tile line in the lawn area tend to be less than rates made in comparable locations in the chicken yard area, i. e., rates of 0.062 and 0.062 inch per hour compared to rates of 0.075, 0.075, 0.065, 0.180, and 0.150 inch per hour. These results confirm the judgment that the outer part of the tile field appeared the better absorption area from a visual examination.

Limited comparisons of the effect of size of percolation hole on the rate obtained are available in the data. These comparisons are tabulated in table 28. The differences in rates obtained in the different-sized holes appear to have no correlation to hole size. In the group of holes north of the tile line, the rates in the 6-inch and 8-inch holes were practically the same; while in the group of holes south of the tile line, the rates of the 8-inch and 12-inch holes were practically the same. Data presented elsewhere in the report show the same trend.

TABLE 28.—Percolation rates as influenced by size of test hole

Location of hole	Type of run	Percolation rate—inches per hour		
		6" round	8" round	12" square
4' north of tile line	Dry.....	0.670	0.900	0.375
	Overnight.....			0.447
	Wet.....	0.810	0.525	0.420
	Average..	0.745	0.712	0.414
4' south of tile line	Dry.....	0.210	0.030	0.075
	Overnight.....		0.136	0.096
	Wet.....	0.100		0.083
	Average..	0.155	0.083	0.085

The data on percolation rates in the chicken yard area are shown diagrammatically in plates 19, 20 and 21. The rates are shown in relative location to each other and in relative location

to the tile lines. A comparison of any of the hole percolation rates show about the same thing, that is, there is a decrease in the absorptive capacity of the soil from a location 4 feet north of the tile line to a minimum at the tile line, and then an increase at locations south of the tile line. The rates south of the tile are not as high as those to the north because they are probably further influenced by the second tile line. The over-all averages of the hole percolation rates according to location are: 0.551, 0.122, trace, 0.100, 0.090, inch per hour, from a location 4 feet north of tile line A to 4 feet south of tile line A at locations on 2-foot intervals. The rates as measured in the confined cylinders show a similar distribution. The rate in the tile trench was not measurable, it was so slow. The soil surface in the trench is evidently almost completely clogged as far as vertical movement of water is concerned. Consequently absorption of effluent from the tile trench must be primarily through lateral movement away from the trench.

The core percolation rates show the same general picture of rate distribution as the hole rates; however, the differences in rates are smaller.

Percolation rates of cores sampled in a horizontal direction were slightly higher than the rates of cores sampled in the vertical direction.

The macro-pore space volumes of the soil cores sampled in the bottoms of all the test holes show no apparent difference between locations. Since Bendixen and Slater (1 2) among others, have shown that the macro-pore space volume is an index of permeability, the potential permeabilities of the soils at the various locations are evidently no different. The differences in rates measured by the hole percolation tests, therefore, must be due to some factor other than inherent soil permeability. The differences may be due to surface sealing, as in the soil directly below the tile line, or due to differences in saturation conditions. The more completely saturated a soil, the slower it will absorb water, other conditions being equal. Therefore the soil near the tile trench is probably completely saturated and the degree of saturation decreases away from the tile trench. This creates a condition favorable for lateral movement of water through the soil away from the tile trench.

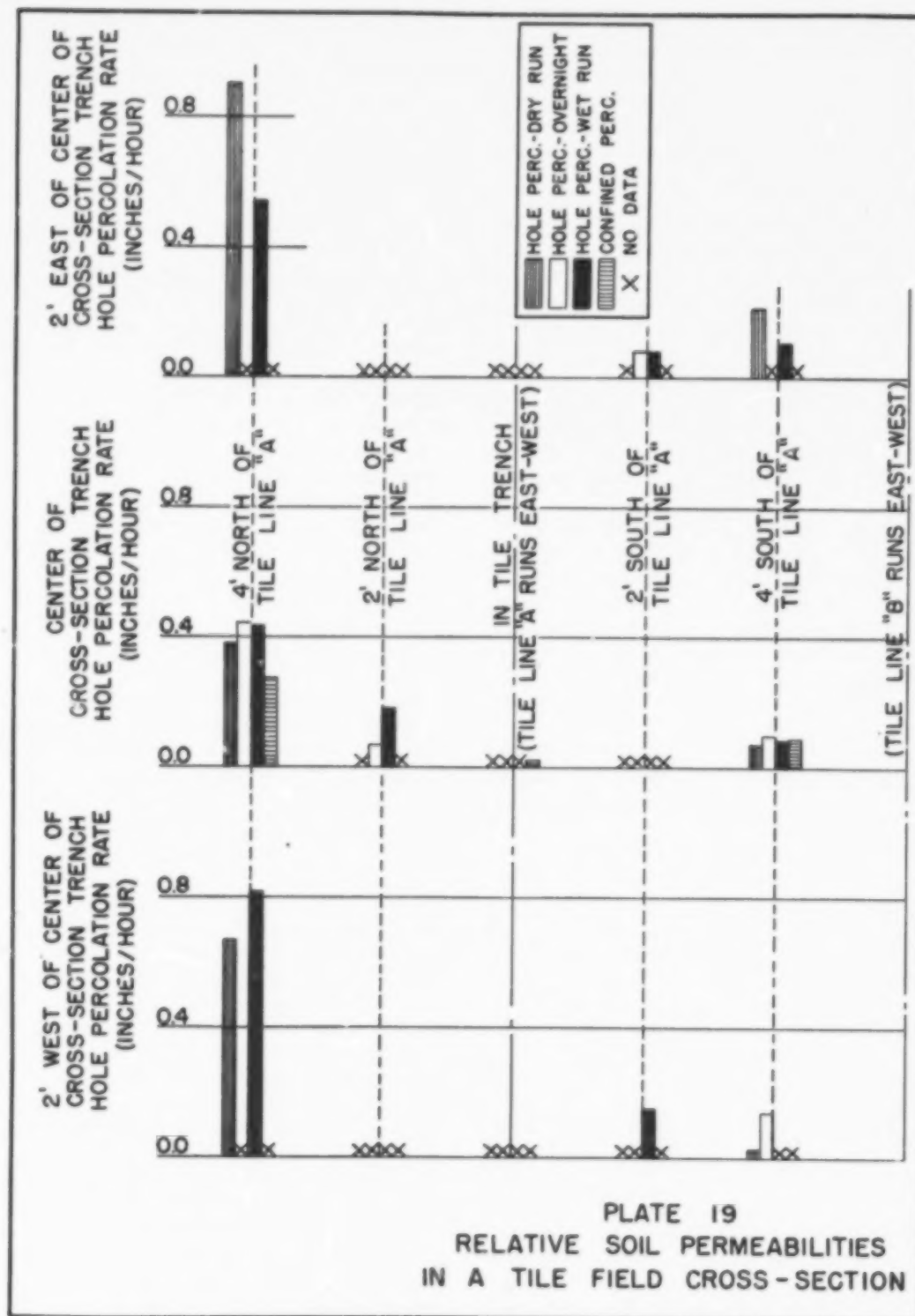
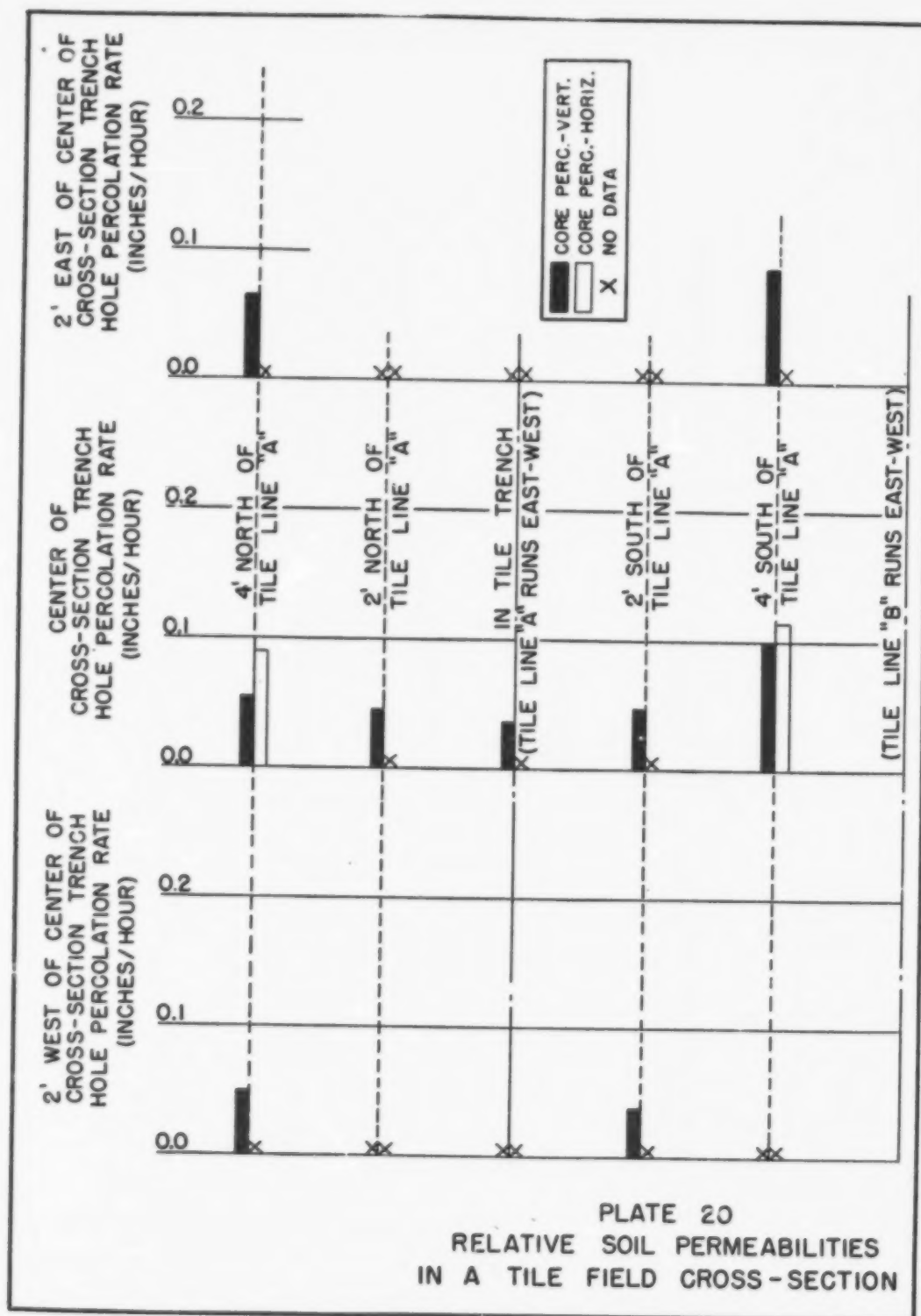
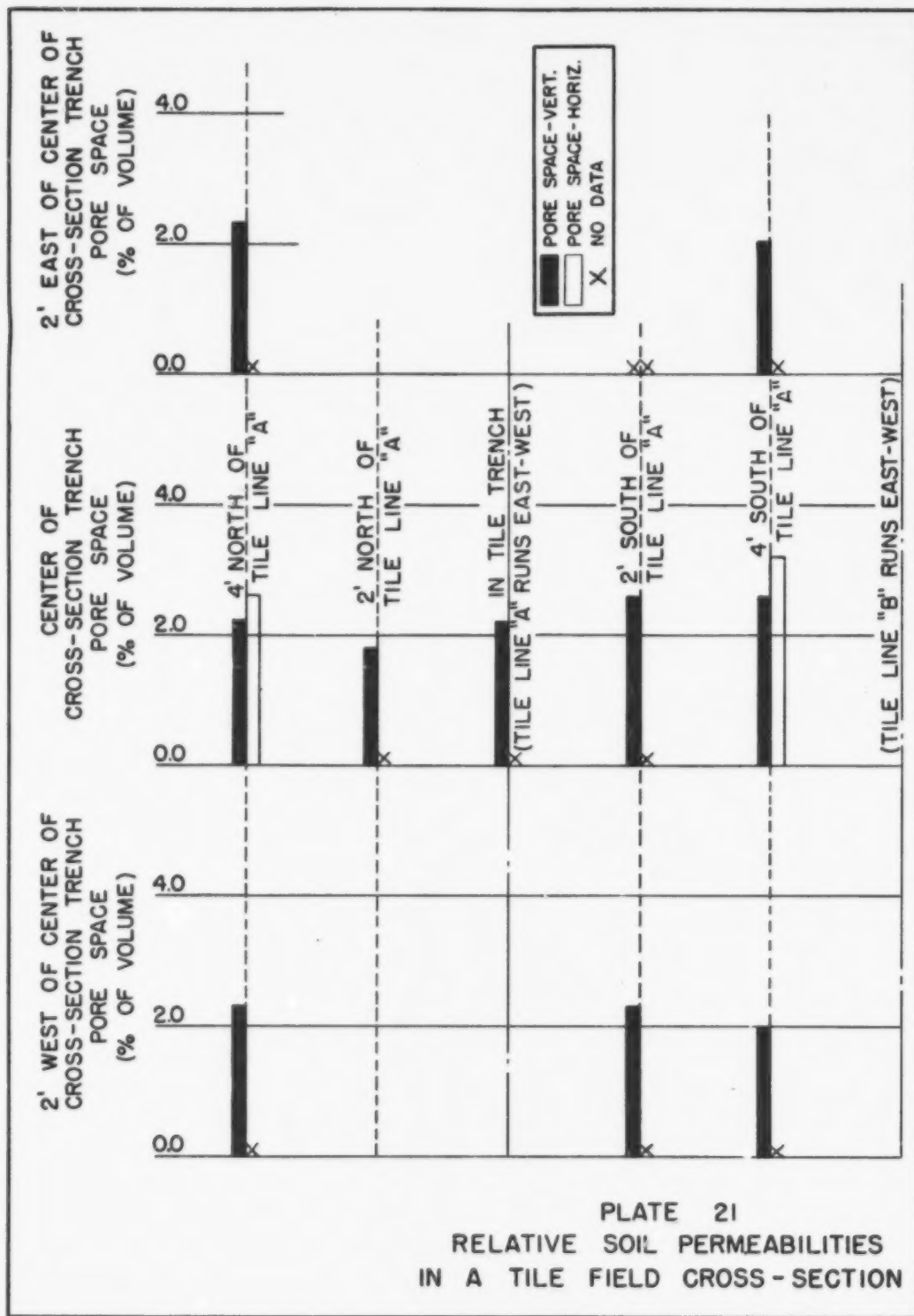


PLATE 19
RELATIVE SOIL PERMEABILITIES
IN A TILE FIELD CROSS-SECTION





The evidence that lateral movement of water is a factor in effluent absorption by this soil suggests the possible use of narrower but deeper trenches for more efficient tile line systems. If the bottom of a trench is to be sealed to vertical movement of water in a relatively short time the main value of a wide trench will be lost. Under such conditions a narrower but deeper trench would offer a larger area for lateral movement and may be more efficient.

It is planned to continue these studies on a variety of soil types and under a variety of moisture conditions.

SUMMARY

Preliminary data on a single operating tile field indicate the following trends:

1. Considerable variation in water absorption properties of a soil may exist within relatively short distances.

2. The size of hole in which percolation tests are made has no effect on the results.

3. The percolation rate distribution across a tile line shows that rates tend to decrease at

locations close to the tile line, possibly due to a more complete degree of water saturation in this area, although other factors may be involved.

4. There is evidence that the efficiency of this particular tile field in disposing of the septic tank effluent must depend a great deal on lateral movement of effluent out of the tile trench.

5. Observation of root distribution in the tile trench of this field showed a concentration of roots in the ground and gravel below the tile line and very few above. No roots were found in the tile itself.

REFERENCES

- (1) Bendixen, T. W., and Slater, C. S., "Effect of Time of Drainage on the Measurement of Soil Pore Space and its Relation to Permeability," *Soil Science Soc. of America, Proc.*, vol. 11, p. 35-42, 1946.
- (2) Bendixen, T. W., Herahberger, M. F., and Slater, C. S., "A Basis for Classifying Soil Permeabilities," *Journal of Agric. Research*, vol. 77, p. 157-168, 1948.

SECTION F

Soil Clogging Effects of Septic Tank Effluents

INTRODUCTION

The causes of soil clogging due to addition of septic tank effluents may be logically separated into three factors: (1) clogging due to a physical action of the solids added, (2) clogging due to biological factors, products formed, etc., and (3) clogging due to a deterioration of soil structure caused by chemical changes in the soil. The possible physical clogging is obvious, it could be merely the stopping up of the pore space in the soil available for water movement by the suspended solids added in the effluent. Biological type of clogging has been shown by Allison (1) to take place in permeability studies on continuously submerged soils. In his case, cores were treated with tap water and "the reduced permeability appears to be entirely due to microbial sealing." Clogging due to a deterioration of soil structure caused by chemical changes in the soil is a common problem in the Western States, where quality of the irrigation water must be carefully controlled. Waters high in sodium when added to the soil cause a deterioration in structure and impaired conditions of permeability. Since any one or all of the above factors may be operative under septic tank tile field conditions it would be desirable to know the relative magnitude of the individual effects in order to provide possible corrective measures.

A study of the relative soil clogging effect of effluent from a tank system having garbage added and of filtered fresh raw sewage (simulating fresh settled sewage) has been included.

Methods

Three series of 12 soil cores each were set up on which to test the relative effects of the factors outlined above. Each series of cores had the following dosing treatments on duplicate cores:

(1) Tank No. 5 (garbage added) disinfected effluent.

(2) Tank No. 5 (garbage added) normal effluent.

(3) Tank No. 9 disinfected effluent.

(4) Tank No. 9 normal effluent.

(5) Fresh raw sewage filtered through a glass wool pad.

(6) Tap water disinfected.

The first series of cores were undisturbed soil of clay loam texture and well structured. They were obtained by forcing a 4-inch steel cylinder 12 inches long 8 inches into the soil. The cores were then carefully dug out and trimmed flush with the bottom end. The cores were brought to the laboratory, saturated, and placed in a funnel device so that the effluent passing through each core could be collected. A half inch of gravel was placed on the surface at each core to prevent disturbance of the core surface and the dosing plan as described above was started.

Difficulty was encountered early with the natural cores because of the great variability between cores and the great variability between daily percolation measurements on individual cores. For this reason the subsequent cores set up for the experiment were manually packed.

Two series of 12 manually-packed soil cores were set up. The same size cylinders as used for the natural cores were used for the manually-packed cores. The soil packed into the cores was a heavy reddish brown clay obtained in the laboratory yard. Enough soil was taken from the one location to pack all of the cores. The soil was allowed to dry partially and then gently crushed to pass a No. 6 sieve (3.35mm.). The soil was mixed well and then packed into the cylinders by the following procedure: A steel cylinder was placed in the funnel device and a 1-inch depth of pea gravel ($\frac{1}{8}$ to $\frac{1}{4}$ inch placed in the bottom. A 1,000 cc portion of the mixed soil was poured into the cylinder and was packed first by rodding for 50 strokes with a $\frac{1}{2}$ -inch steel rod raised and dropped through a 6-inch stroke and then further packed by

tamping for 50 strokes with a 2-inch tamper on the end of a 1/2-inch rod. Successive 1,000 cc aliquots of soil were added and the packing continued until an 8-inch column of soil was packed. The height of the core was carefully trimmed to 8 inches and 1 inch of pea gravel was placed on the core surface. All cores were then dosed with tap water until they were saturated and until an initial percolation rate was obtained. The planned effluent dosing treatment as described previously was then started. The percolate volumes from the cores were measured daily and the cores were all dosed daily, adding the appropriate effluent in volumes based on the previous days' percolation. It was the aim to add just enough effluent daily to maintain a free head of liquid on the cores at all times. Measurements of the volume of effluent added to each core and passing through each core were recorded daily. Solids analyses of the effluents used are available. Percolation rates, decrease in percolation rates, and amount of solids added to the cores were all calculated daily and will afford a comparison of the treatment effects.

The methods available for disinfection of the septic tank effluents were limited. The use of any disinfectant that might also affect the soil chemically was prohibited by the nature of the

experiment. This eliminated such disinfectants as mercuric chloride. Also the use of any disinfectant that might affect the surface tension of water, such as toluene, carbon bisulfide, etc., was eliminated. For practical reasons of operation the possible use of any gaseous disinfectants was discarded. With the majority of the available disinfectants eliminated, it was decided to use formaldehyde.

In order to select the proper concentration of formaldehyde for the most efficient disinfection of the septic tank effluents, the following test was run: A series of samples was taken of the effluents that were to be used in the core dosings in sterile bottles. To these samples, enough formalin was added to bring the concentration of formaldehyde to 0 p.p.m., 10 p.p.m., 100 p.p.m., 500 p.p.m., and 1,000 p.p.m. The samples were allowed to stand for 24 hours and then aliquot samples were removed on which to make plate counts; another series of aliquot samples was removed after 48 hours of standing. Bacterial plate counts were made using nutrient agar and incubating at 37° C. for 24 hours. The results are tabulated in table 29. The 1,000 p.p.m. concentration seems to give the most efficient disinfection. This concentration agrees with that used by Allison (1) and other investigators.

TABLE 29.—Relative efficiency of disinfection of septic tank effluents with various concentrations of formaldehyde

Effluent sample	Time of contact	Bacterial plate count,* concentration of formaldehyde				
		0 p. p. m.	10 p. p. m.	100 p. p. m.	500 p. p. m.	1,000 p. p. m.
	<i>Hours</i>					
Tank No. 5.....	24	1,000,000/ml.	630,000/ml.	26,000/ml.	290/ml.	80/ml.
Tank No. 5.....	48	1,700,000/ml.	2,700,000/ml.	231,000/ml.	640/ml.	18/ml.
Tank No. 9.....	24	230,000/ml.	250,000/ml.	25,000/ml.	180/ml.	150/ml.
Tank No. 9.....	48	410,000/ml.	1,400,000/ml.	45,000/ml.	270/ml.	9/ml.

* Plate count made on nutrient agar incubated at 37°C. for 24 hours.

RESULTS AND DISCUSSION

Natural Cores

Due to inherent soil characteristics, the natural soil cores were quite variable as to percolation rates obtained—both between individual

cores and between days on single cores. In fact, two cores, which were being treated with tank No. 5 (garbage) disinfected effluent were so extremely variable they had to be discarded. Examination of these cores showed them to be permeated with earthworm holes which made

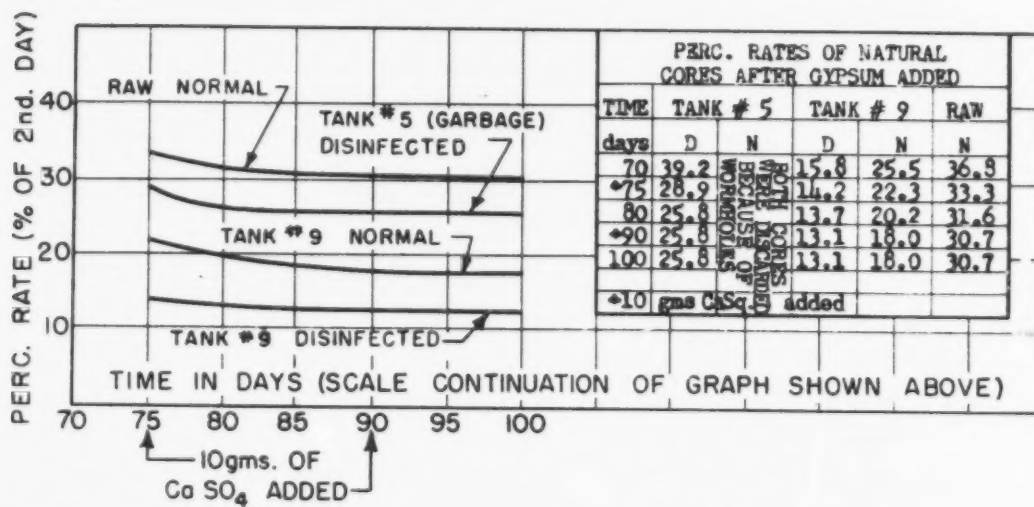
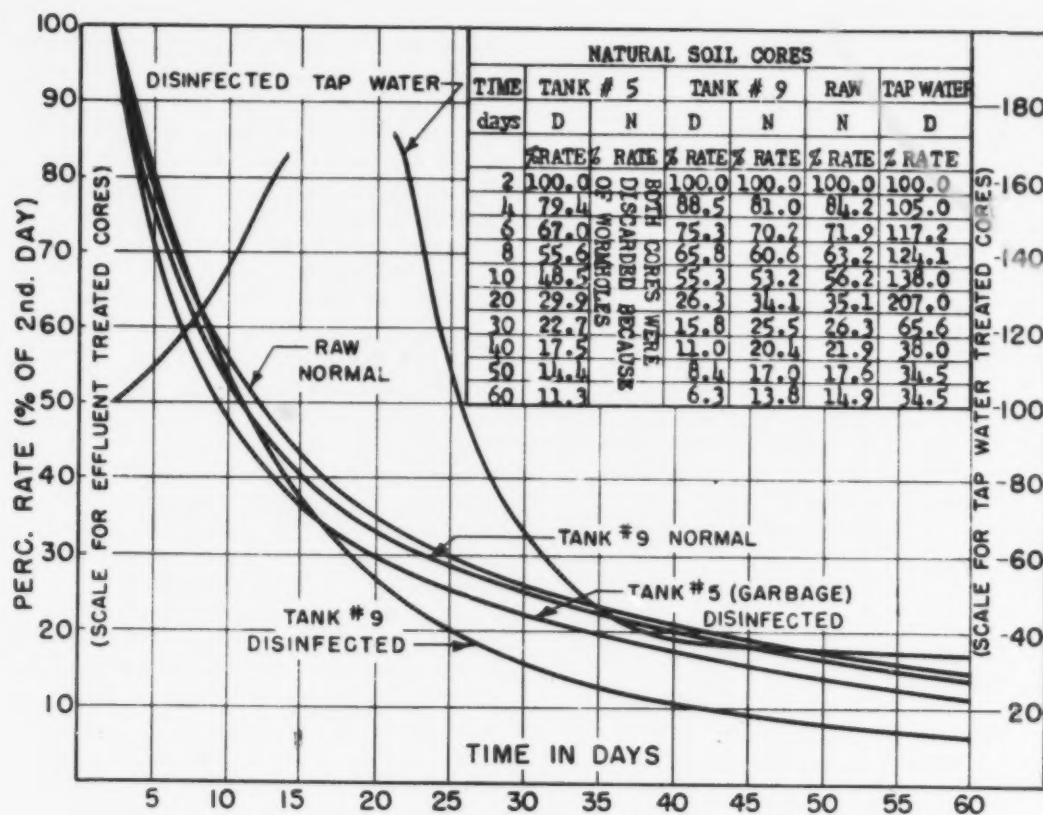


PLATE 22

RATE OF CLOGGING OF NATURAL
SOIL CORES AS RELATED TO TIME

N = NORMAL
D = DISINFECTED

them useless for the purpose of the experiment. Data on the remaining cores indicate some interesting trends. The curves of the average daily percolation rates (calculated in percentage of the starting rate) plotted against time are shown in plate 22.

The cores treated with disinfected tap water show the least decrease in percolation rate, or the least clogging as we shall refer to it, of all the treatments. The curve is more or less typical, an increase in rate for the first part of the curve and then a gradual decrease. At the end of 60 days the rate had decreased to about 35 percent of the original rate.

Comparison of the disinfected and normal effluent treatments indicate that the disinfected effluents tend to clog the soil to a greater extent than the normal effluents. The percolation rates of the cores treated with tank No. 9 effluent, disinfected, decreased to about 6 percent of the original rate whereas the same effluent, normal, decreased the rate to 14 percent of the original.

These curves offer no comparison of the relative effect on clogging between the effluent from the tank with garbage added and the effluent from the tank with no garbage added, as part of the cores treated with garbage effluent was discarded.

In order to check the effectiveness of the disinfection treatments, bacterial plate counts were made at intervals to get an index of the relative levels of bacterial populations both in the effluents and in the soils. The results are tabulated in table 30.

On the first day of the run there seemed to be no difference in the soil population levels. Evidently the formaldehyde had not had a long enough contact time to have any disinfecting effect. On the second day there seemed to be a difference in both the soil population and the effluent population. The populations in the soil and in the effluent under the disinfected treatments are lower in all cases. Treatment with formaldehyde seems to be giving at least a relative disinfection.

TABLE 30.—Bacterial population* of the different soils and effluents used in the soil clogging experiment (natural cores)

Time in days from start of experiment		Core treatment—(type of effluent used for core dosing)					
		Tank No. 5 (garbage) effluent		Tank No. 9 (no garbage) effluent		Filt. raw sew.	Tapwater
		Disinfected	Normal	Disinfected	Normal	Normal	Disinfected
1	Soil**: top 1 inch in core.....	600,000/gm.	540,000/gm.	600,000/gm.	540,000/gm.	540,000/gm.	540,000/gm.
	Bottom 1 inch in core.....	-----	-----	-----	-----	-----	-----
	Effluent: Added to core.....	8,000/cc.	-----	60/cc.	-----	-----	-----
	Passed thru core.....	-----	-----	-----	-----	-----	-----
2	Soil: Top 1 inch in core.....	254,700/gm.	101,232,000/gm.	-----	-----	-----	-----
	Bottom 1 inch in core.....	-----	-----	-----	-----	-----	-----
	Effluent: Added to core.....	360/cc.	470,000/cc.	30/cc.	350,000/cc.	-----	-----
	Passed thru core.....	-----	-----	-----	-----	-----	-----
60	Soil: Top 1 inch in core.....	80,000,000/gm.	720,000/gm.	1,600,000/gm.	800,000/gm.	220,000/gm.	2/gm.
	Bottom 1 inch in core.....	500/gm.	120,000/gm.	200/gm.	290,000/gm.	180,000/gm.	800/gm.
	Effluent: Added to core.....	5/cc.	2,900,000/cc.	40/cc.	480,000/cc.	1,380,000/cc.	1/cc.
	Passed thru core.....	70/cc.	230,000/cc.	1/cc.	95,000/cc.	3/cc.	2/cc.

* Population reported is based on plate counts made on nutrient agar media incubated at 37° C. for 24 hours.

** All unit weights this table refer to saturated soil.

At the end of the experiment there was an unexplained increase in the soil population in the top 1 inch of soil of the disinfected cores. Whether this is a true index or an experimental error is unknown. The method of sampling the soil on which the plate counts were made was of necessity rather crude and open to wide experimental error. The least contamination during the sampling procedure could introduce large errors in the final plate counts. It is felt therefore that the extremely high plate counts on the surface inch of the sterile soils are possibly due to experimental errors.

An interesting observation is seen in table 30 in comparing the relative populations of the top inch and the bottom inch of the soil. The top inch of soil tends to have a higher population. Also of interest is the comparison of bacterial numbers in the effluent added to the core as compared to those of the effluent after it has passed through the core, particularly of the normal effluents. The results indicate that, for this soil, a column as shallow as 8 inches can be an efficient filter in removing bacteria from percolating water. However, such efficiency may depend on the specific physical circumstances of a soil with respect to structure, fissuring, channeling, wormholes, rootholes, etc.

The disinfected tap water and the respective soil show relatively effective disinfection under all conditions.

After the natural cores had been run until they were considered clogged, effluent treatments were stopped and the cores allowed to dry out. After 15 days of drying, 10 grams of gypsum (CaSO_4) were added to each core and the effluent dosings continued. Another 10 grams of gypsum were added to each core after 15 days. The addition of CaSO_4 was made on the assumption that if the previous soil clogging had been caused by chemical factors, the addition of the gypsum might alleviate the clogged condition. The common chemical change in the soil that causes reduced permeability is caused by sodium replacing the calcium and other bases in the base exchange complex which results in a deterioration of structure. It is conceivable that if the sodium could then be replaced (the reaction is reversible) in the soil complex, the structure and the permeability could be improved.

The addition of gypsum to the cores did not

produce any measurable increase in percolation rates—as can be seen on plate 22. The improvement of structure may require wetting and drying cycles as well as the removal of sodium. This experiment did not meet these conditions.

The relative percolation rates for the different treatments shown on the upper graph in plate 22 are not directly comparable to the rates shown on the lower graph in plate 22 since the soil conditions in the period between the 60th and 70th days, when the cores were not being dosed, varied among the cores. All dried out somewhat during this period but some dried longer than others, which affected the rates when the feeding was started again.

Since the data on the natural cores were so variable the trends are inconclusive. The experiment was repeated with two sets of manually packed soil cores. The packed cores were expected to reduce some of the inherent variability. The elimination of flaws such as root channels, wormholes, etc., should result in more homogeneous conditions within the cores.

Manually-Packed Cores

The average daily percolation rates, calculated as a percentage of the original rate, for the different effluent treatments for both series of manually-packed cores plotted against time are shown on the upper graph of plate 23. Each curve is the average curve for four soil cores. The data on duplicate cores within each series are averaged by the five-point moving average method, the center point of the five-point group being used as the plotting point. The average of the two series was then calculated for each treatment. These are the values shown in table 31 and plotted on plate 23 against time. The average percolation rates (in percent of original rate) of duplicate cores are plotted on plates 32, 33, and 34. (Plates 30 through 37 are in appendix B, pp. 86 to 94). The average of duplicate cores grouped by series is shown on plate 30.

It is again evident, as with the natural cores, that the disinfected effluent-treated cores clog faster and to a greater degree than the normal effluent-treated cores. The percolation rates of the disinfected effluent-treated cores (plate 23) were reduced to 7.4 and 8.7 percent of their original rates for tank No. 9 and tank No. 5

(garbage) effluent treatments respectively. The rates for the corresponding normal effluent-treated cores were reduced to 19.3 and 16.0 percent respectively. The normal filtered fresh sewage-treated cores fell between these two groups at 12.2 percent of the original rate; that is, the fresh sewage caused greater clogging than the normal effluents, but less clogging than the disinfected effluents.

Looking at plate 30 it can be seen that the order of clogging due to the different treat-

ments is the same for the two series of cores.

Since the disinfected effluents seem to clog the soils faster and to a greater degree than the normal effluents, it may be inferred that the solids added to the cores have a greater effect on clogging than does the biological activity after the effluent is added to the soil. The biological activity may, by digestion of solids in the soil, have a net result of decreasing the clogging effect of the effluent.

TABLE 31.—Rate of clogging of packed soil cores as related to time and the amount of suspended solids added

Averages of No. 1 and No. 2 Series of Cores										
Tank No. 5 (garbage)					Tank No. 9 (garbage)				Filt. raw	
Disinfected		Normal		Time (days)	Disinfected		Normal		Normal	
Percent rate	S. S.*	Percent rate	S. S.*		Percent rate	S. S.*	Percent rate	S. S.*	Percent rate	S. S.*
100.0	0.353	100.0	0.352	3	100.0	0.240	100.0	0.312	100.0	0.306
81.2	0.438	77.6	0.438	4	79.7	0.394	79.2	0.384	71.8	0.384
69.6	0.514	66.0	0.507	5	68.5	0.458	69.8	0.442	56.4	0.450
61.0	0.575	57.6	0.566	6	61.1	0.514	63.8	0.494	48.2	0.515
54.4	0.624	51.4	0.614	7	55.5	0.564	59.9	0.545	44.4	0.567
49.2	0.654	46.6	0.661	8	50.9	0.619	56.4	0.598	39.4	0.616
44.4	0.697	43.2	0.704	9	47.4	0.674	53.3	0.656	36.0	0.660
40.8	0.736	39.6	0.742	10	43.6	0.728	51.2	0.705	33.7	0.701
27.6	0.882	29.8	0.908	15	33.7	0.926	43.7	0.932	26.2	0.898
20.5	0.992	25.2	1.030	20	27.8	1.116	38.8	1.161	22.1	1.058
13.4	1.134	22.8	1.241	30	20.6	1.464	32.8	1.584	17.6	1.249
10.8	1.253	22.7	1.574	40	15.0	1.708	28.0	1.979	15.1	1.422
9.4	1.366	17.8	1.977	50	10.8	1.918	23.8	2.554	13.5	1.602
8.7	1.470	16.0	2.152	60	7.4	2.036	19.3	2.826	12.2	1.793

* Accumulated suspended solids added, in grams.

The cores that were treated with normal effluent from a septic tank with garbage added (tank No. 5) seem to clog at a faster rate and to a greater extent than the cores treated with normal effluent from a tank not having garbage added (tank No. 9). The same tendency does not hold for the cores treated with disinfected effluent from the respective tanks. In Series One clogging was about the same by the garbage and the non-garbage effluents. In Series Two the disinfected garbage effluent caused a little less clogging.

Analyzing the data in a different manner, the percolation rates have been plotted against the accumulated amount of suspended solids (in grams) that were added to the cores daily.

The same type of averaging as used for the rates was used for the suspended solids data. The over-all averages of both series are plotted in the lower graph on plate 23 and the averages of duplicate cores, in plates 35, 36 and 37. The average of duplicate cores grouped by series is shown on plate 31.

All of the curves of percolation rates vs. accumulated suspended solids tend towards a straight line at their beginnings. The curves also tend to parallel each other up to the point where from half to three-fourths of a gram of suspended solids has been added (5 to 10 days of operation). These observations indicate that, over this part of the curve at least, the soil clogging effect of the effluents is directly

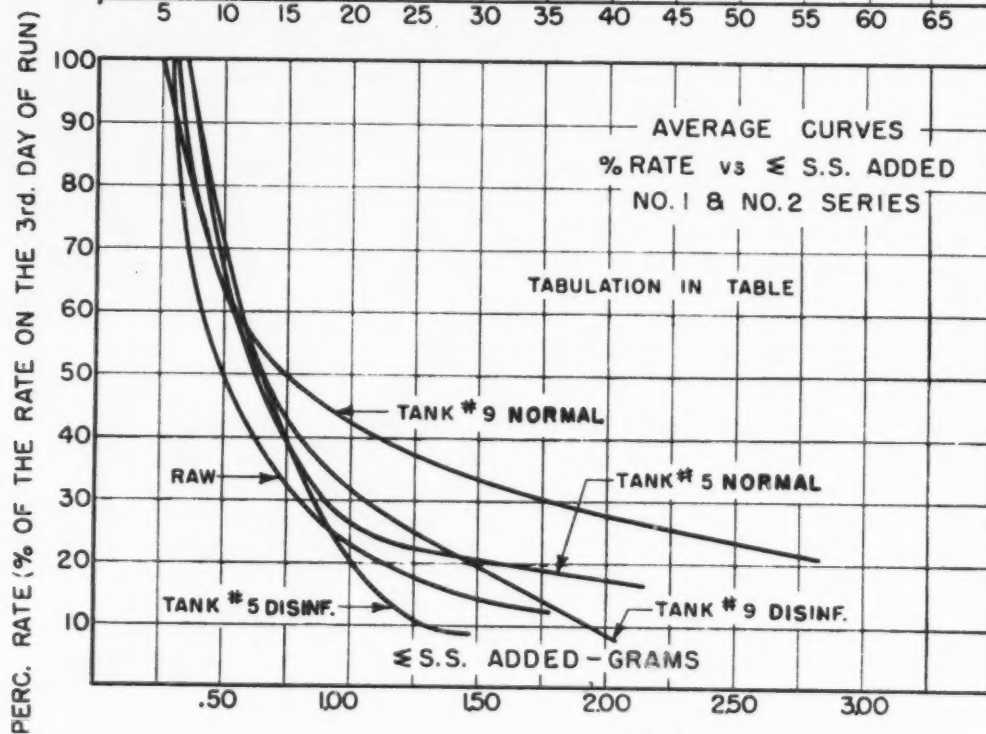
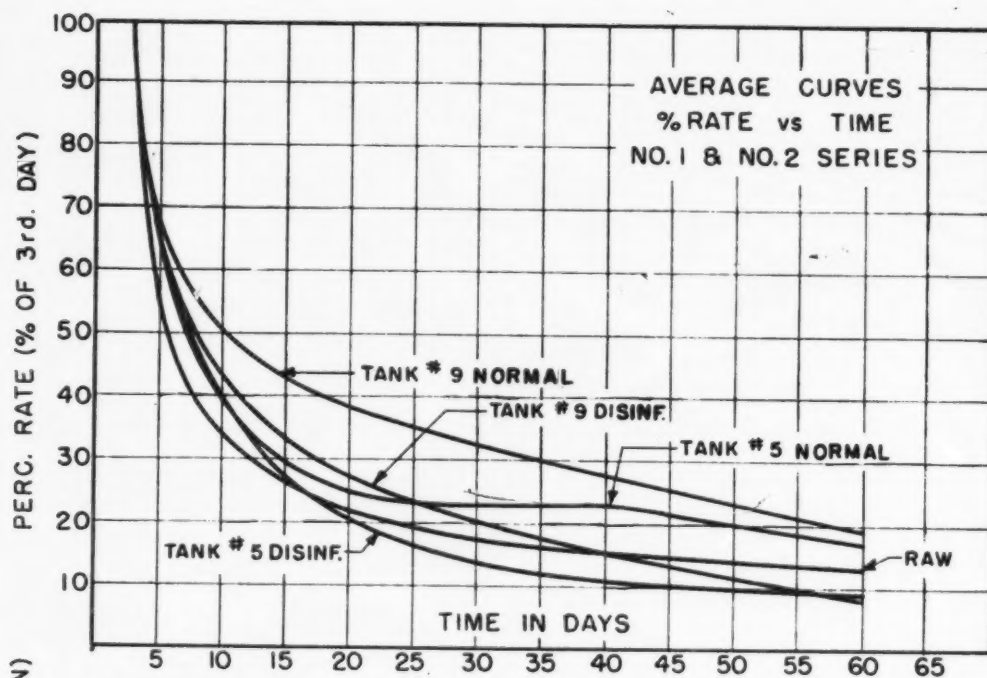


PLATE 23
RATE OF CLOGGING OF PACKED SOIL CORES
AS RELATED TO TIME AND TO THE AMOUNT
OF SUSPENDED SOLIDS ADDED

proportional to the amount of suspended solids added. The curves then flatten out and diverge from their parallelism. The curves of the normal-effluent-treated cores flatten out faster and at a higher level than the curves of the disinfected-effluent-treated cores. Evidently at this diverging point some factor other than the suspended solids begins to have an effect on the clogging.

The point where the curves begin to diverge may be interpreted as the point where biological activity begins to have an effect on the soil clogging. If this be true, the biological activity has a lesser effect on clogging or a greater effect on reducing clogging in the normal effluent treatments compared to the disinfected effluent treatment. It would therefore seem that in the normal treatments there may be a digestion of suspended solids resulting in a reduced clogging that is not happening in the disinfected treatments.

Trends toward the same relative effects of the different treatments on soil clogging shown by the time curve comparison were also in evidence in the suspended solids curve comparison. The normal effluent dosings cause less clogging than disinfected effluent dosings. Effluent from a septic tank having garbage added shows a tendency to clog the soil to a greater extent than effluent from a septic tank not receiving garbage. Filtered fresh sewage seems to cause greater clogging than the septic tank effluents. However, it must be remembered that these trends are based on a limited number of tests and on only one soil. Before definite conclusions can be drawn additional data on a wide variety of soils are needed.

It is interesting to note that in all cases the original percolation rate was reduced to at least 20 percent by the end of the run.

An estimate of the comparable life of these cores under tile field conditions can be made if it may be assumed that the core rates at the beginning of the experiment are comparable to rates determined by an in-place percolation measurement on a similar soil. This is not a strictly true assumption, but for our purpose here may be valid. The permissible loading rate for this soil under tile field conditions is 0.10 gallon per square foot per day according to the Ryon curve. The average amount of suspended solids that had been added to the cores

at the end of the run was 2.055 grams per core area or 25 grams per square foot. The average concentration of suspended solids in the septic tank effluents is 140 p.p.m. Now, if the soil were fed at the rate of 0.10 gallon per square foot per day with an effluent of 140 p.p.m. concentration of suspended solids, it will take 472 days to accumulate 25 grams of suspended solids. In other words the 2-month test on the soil in the laboratory may be considered equivalent to about 16 months of tile field operation.

Since all of the core rates decrease to 20 percent or less during the experiment, we might expect the same soil in a tile field to decrease in its absorption capacity to approximately 20 percent over a 16-month period. Until more information is obtained consideration might be given to the above, that is, a percolation rate as determined by percolation test should be decreased by 80 percent to approximate the rate that the soil would take effluent under tile field conditions. This does not take into account that part of absorption that might take place laterally, or the fact that addition of solids to the field is slower than to the cores and that there may be greater biologic activity in the field; consequently the useful life of a tile field might extend beyond the period mentioned above.

Of course the field percolation rate as determined by an in-place hole percolation method may and probably does need a further correction to adjust the inherent difference between the hole rate and the over-all tile field rate due to such factors as area, conditions of saturation, soil variations, etc.

It is not inconceivable that such adjustments can be arrived at—the over-all adjustment is apparent from studies such as the Ryon work.

SUMMARY

1. Soil clogging experiments were designed primarily to separate soil clogging effects due to physical, biological, and chemical causes. The trends at the present time based on examination of one soil indicate that the clogging during the first several days of dosing of the soil columns is directly proportional to the amount of suspended solids added to the soil. Biological activity in the soil (or on the soil surface) then

appears to take effect and reduces the rate of soil clogging. The greater the biological activity, the slower is the clogging.

2. Effluent from a septic tank having garbage added seemed to cause more clogging than effluent from a septic tank receiving no garbage. This trend does not hold for disinfected effluents from the same tanks. Filtered fresh sewage seemed to clog the soil to an extent intermediate between the normal and the disinfected septic tank effluents. The fresh sewage (which was not disinfected) caused more clogging than the normal effluents but less clogging than the disinfected effluents. All of these trends are based on a limited amount of data on one soil type and should not be regarded as being conclusive.

3. During the 60 days' life of soil cores dosed with normal septic tank effluent, roughly equivalent to 16 months' absorption field operation for the same soil, on the basis of the total suspended solids applied per unit soil area, there

was about an 80 percent reduction of the original percolation rate. However, because of slower rate of addition of solids in the field, the possibility of greater biologic activity, and the opportunity for lateral absorption, as compared with the limited circumstances of the core experiment, it is possible that the comparable life of a tile field in the particular soils studied would extend beyond the 16-month period for the same change in percolation rate.

4. Due to the conditions of the soil cores when gypsum was added, no conclusions can be reached at present on the effect of gypsum on percolation characteristics of a soil. Future runs under controlled conditions will be made.

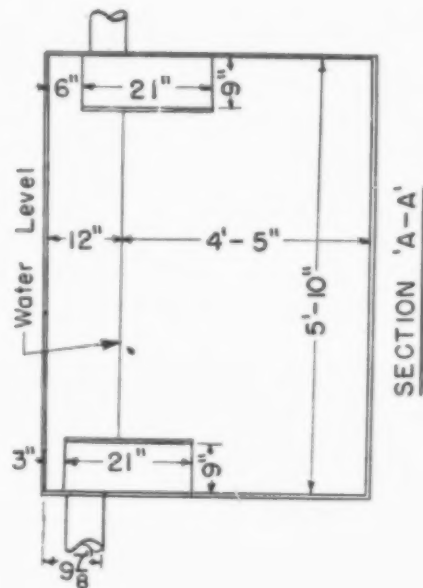
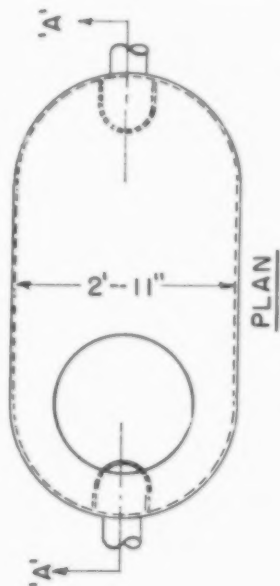
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- (1) Allison, L. E., "Effect of Microorganisms on Permeability of Soil under Prolonged Submergence." *Soil Science*, 63: p.439-450, 1947.

APPENDIX A

Septic Tank Compartmentation Studies

TANK # 2 - ROUNDED END



TANK # 5 - OVAL SHAPED

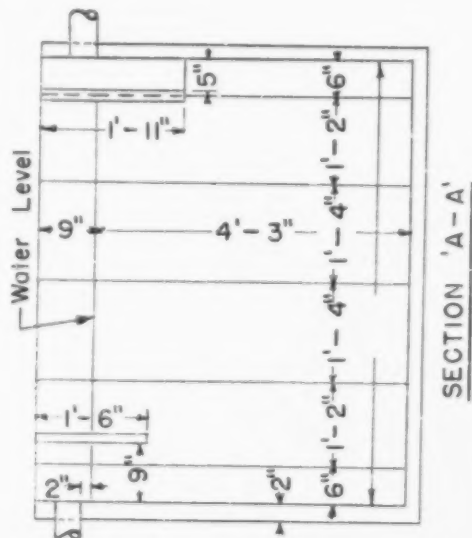
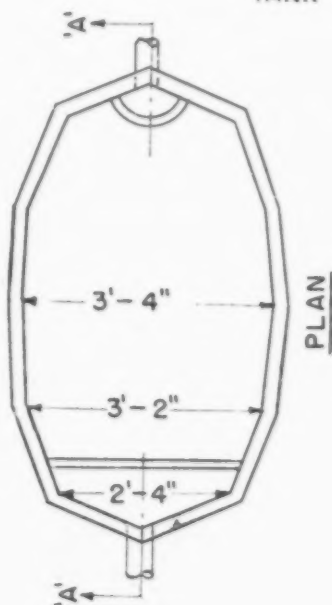
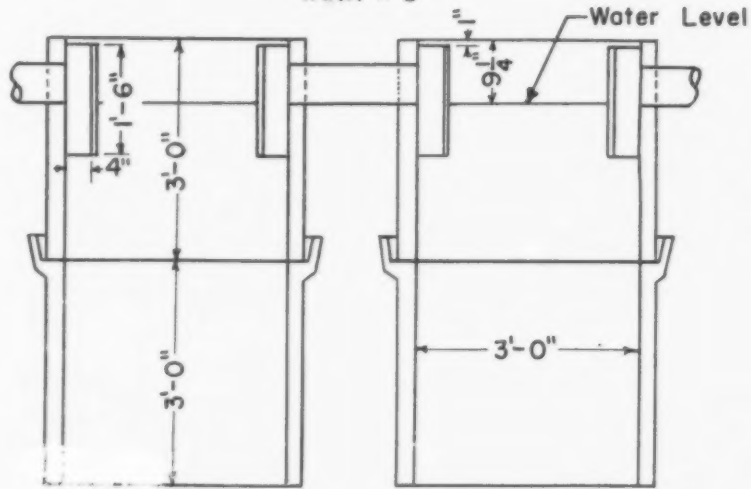


PLATE 24

VERTICAL CYLINDRICAL TANKS

TANK # 3



TANK # 4

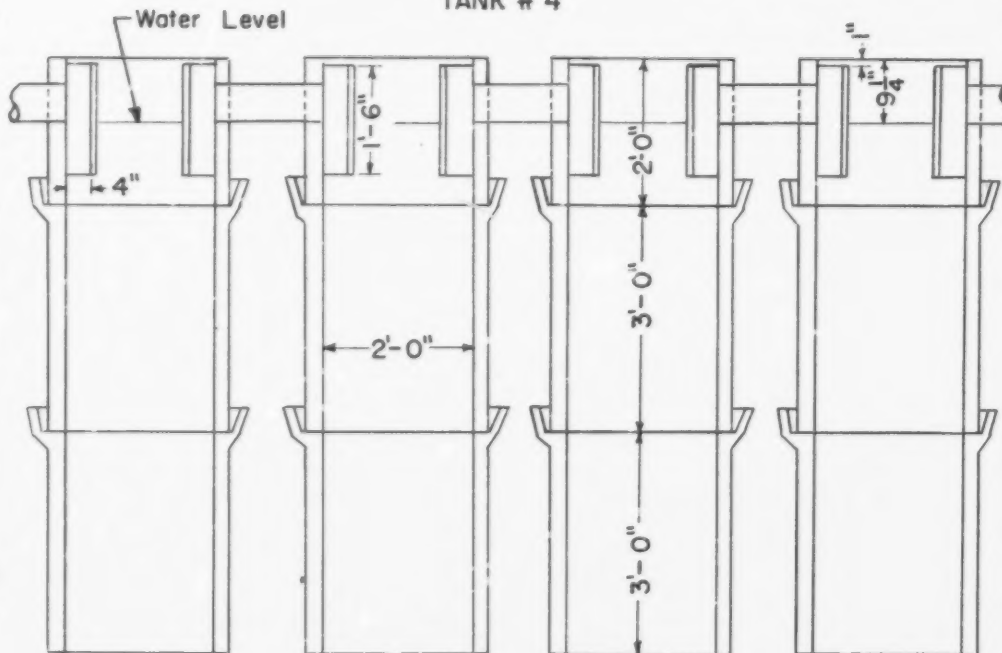
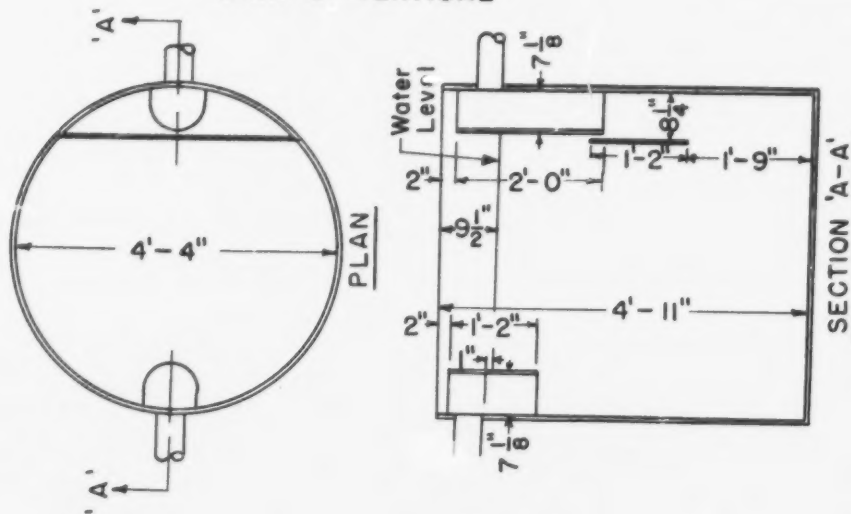


PLATE 25

CYLINDRICAL TANKS

TANK #6 - VERTICAL



TANK #8 - HORIZONTAL

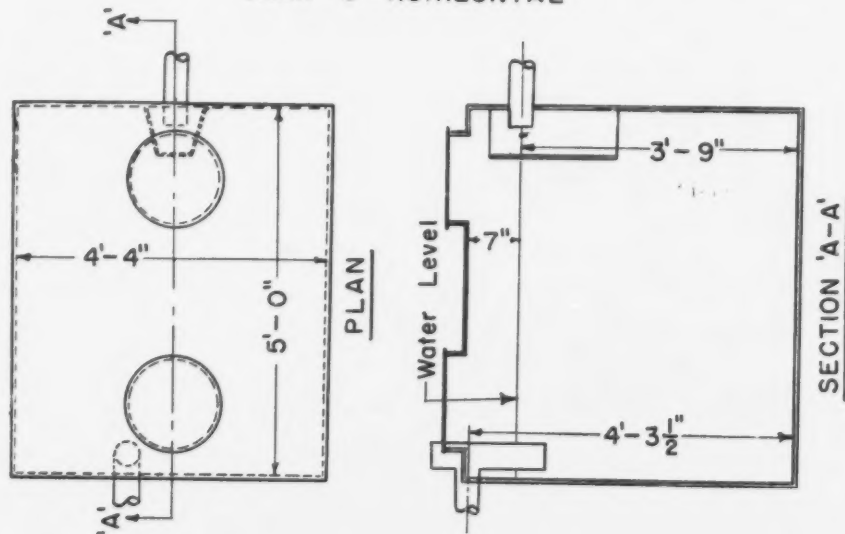
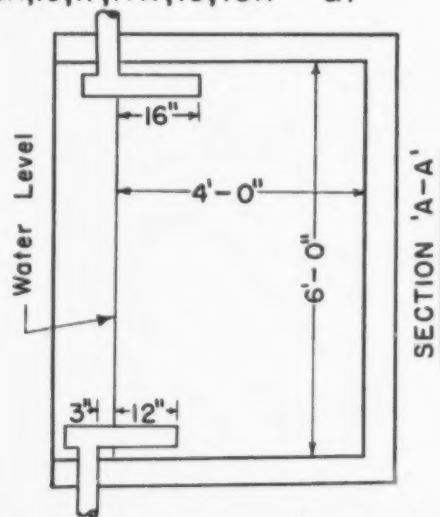
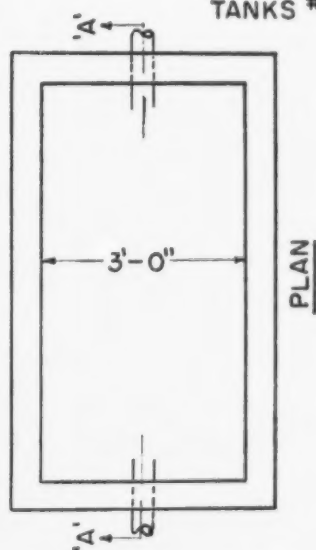


PLATE 26

RECTANGULAR TANKS
TANKS # 7, 9, 9A, 10, 11*, 17A, 18*, 18A*** & 1°



* Tank #11 had a weir outlet

** Tank #18 - Water depth = 3'-0"

*** In Tank #18A, the inlet fixture was varied

° TANK #1 - 5' width,
5' depth & 11' length

TANKS # 7A, 16

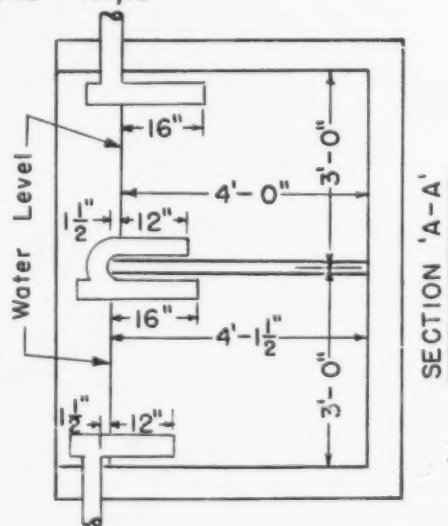
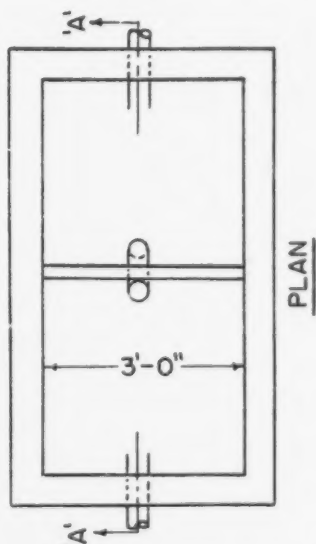
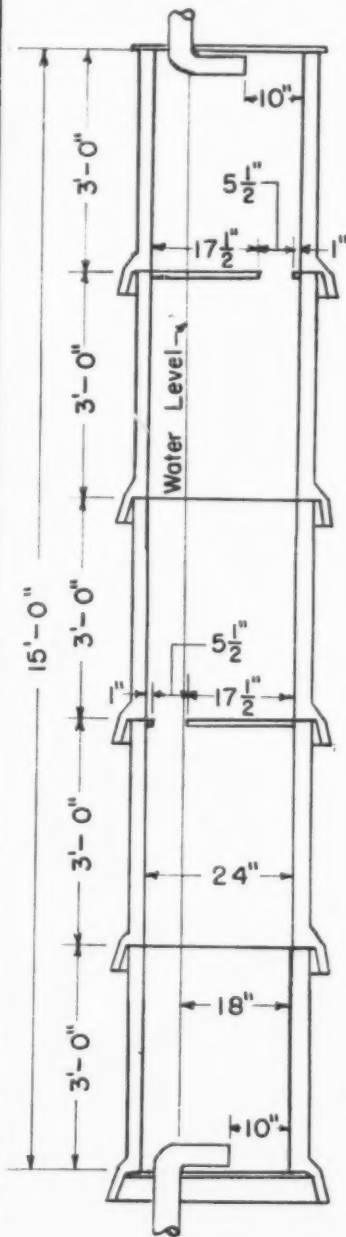


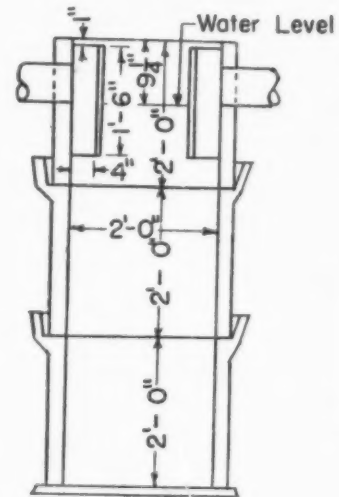
PLATE 27

CYLINDRICAL TANKS

TANK 14 - HORIZONTAL



TANK 12 - VERTICAL



TANK 13 - VERTICAL

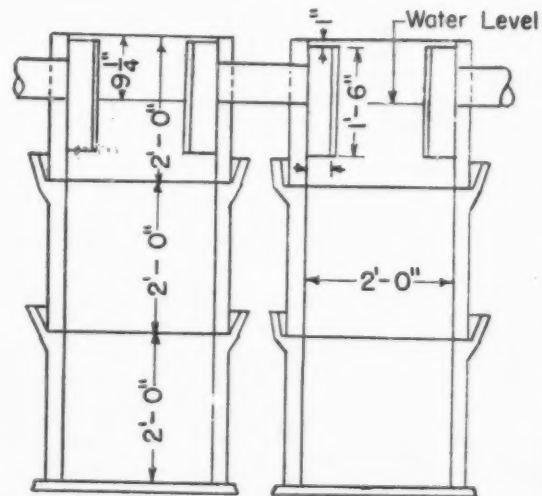
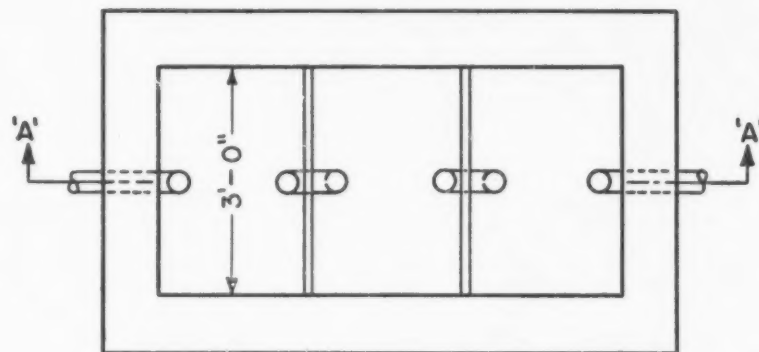


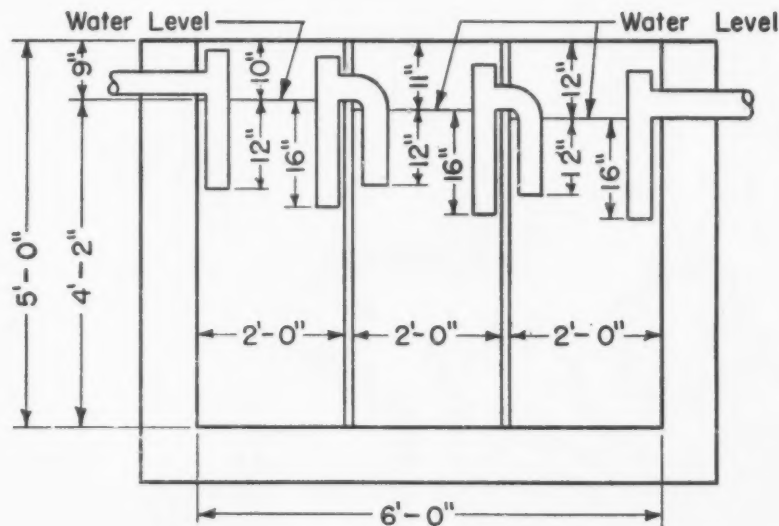
PLATE 28

RECTANGULAR TANKS

TANKS #19,15A*,16A**



PLAN



SECTION 'A-A'

* Tank #15A- 4' Water depth throughout

**Tank #16A-Inter compartment fixtures varied,
4' water depth throughout

PLATE 29

APPENDIX B

Soil Clogging Effects of Septic Tank Effluents

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- 85 -

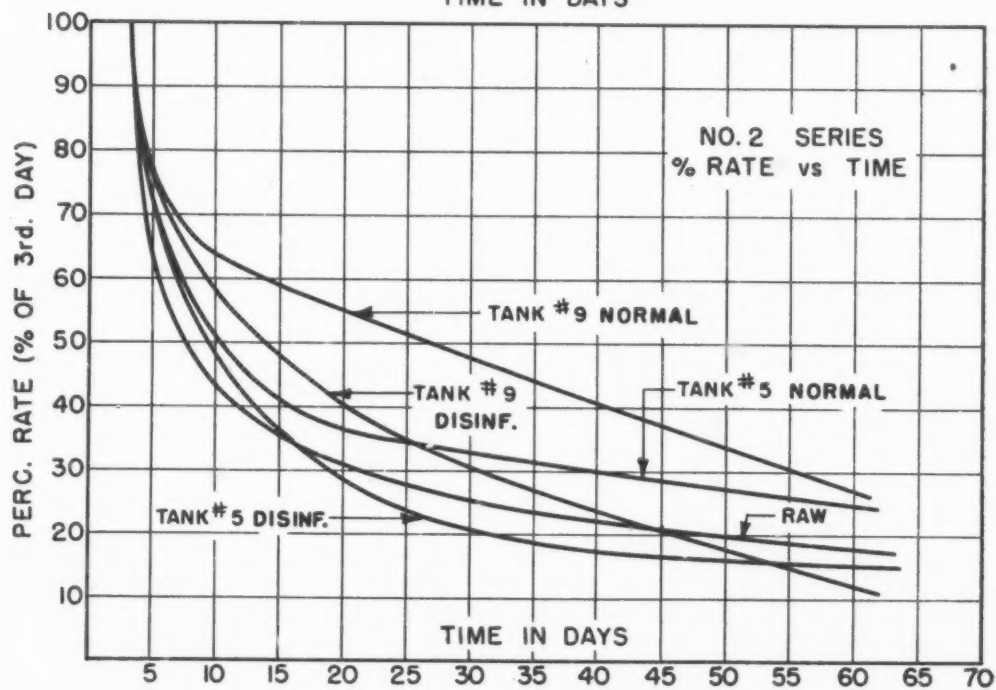
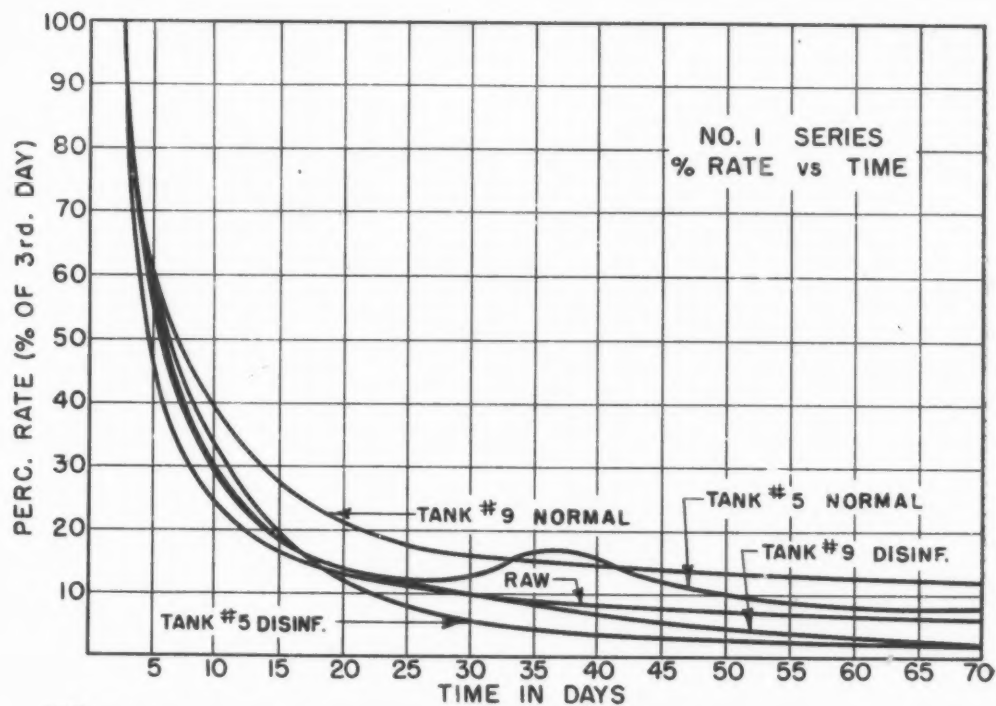


PLATE 30
RATE OF CLOGGING OF PACKED
SOIL CORES AS RELATED TO TIME

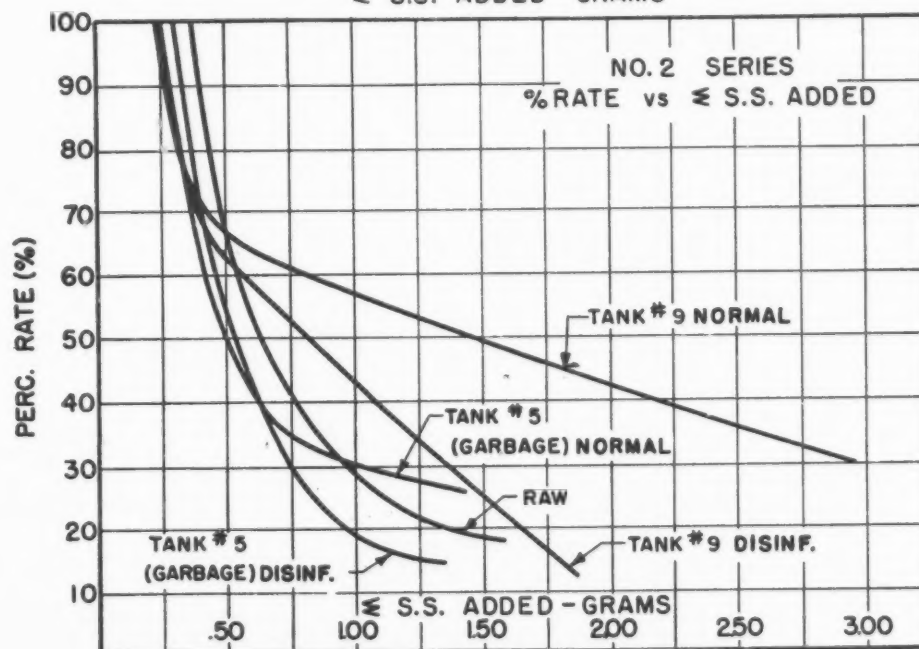
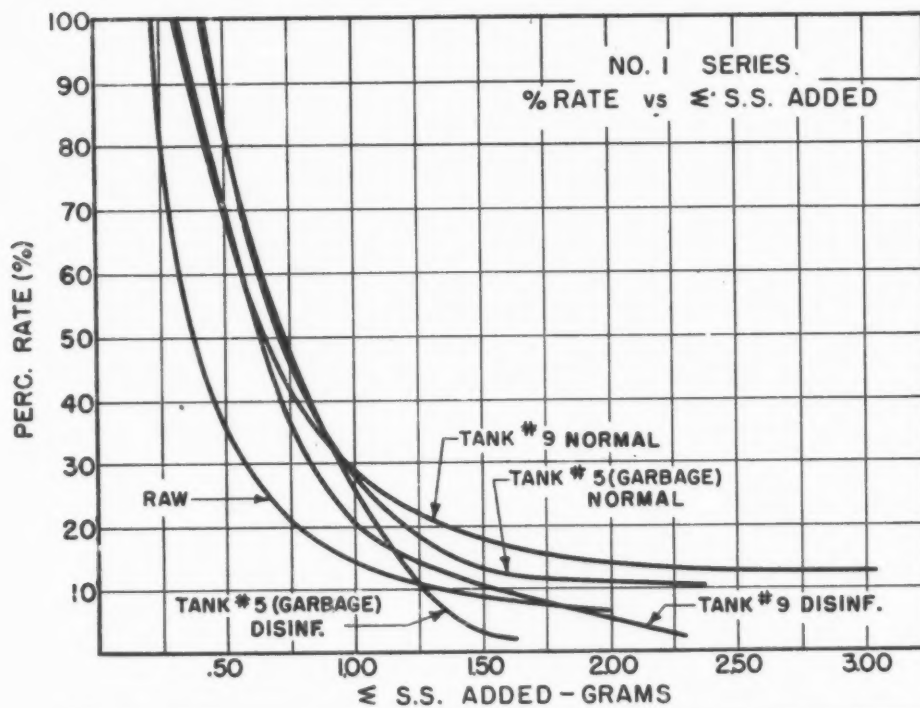
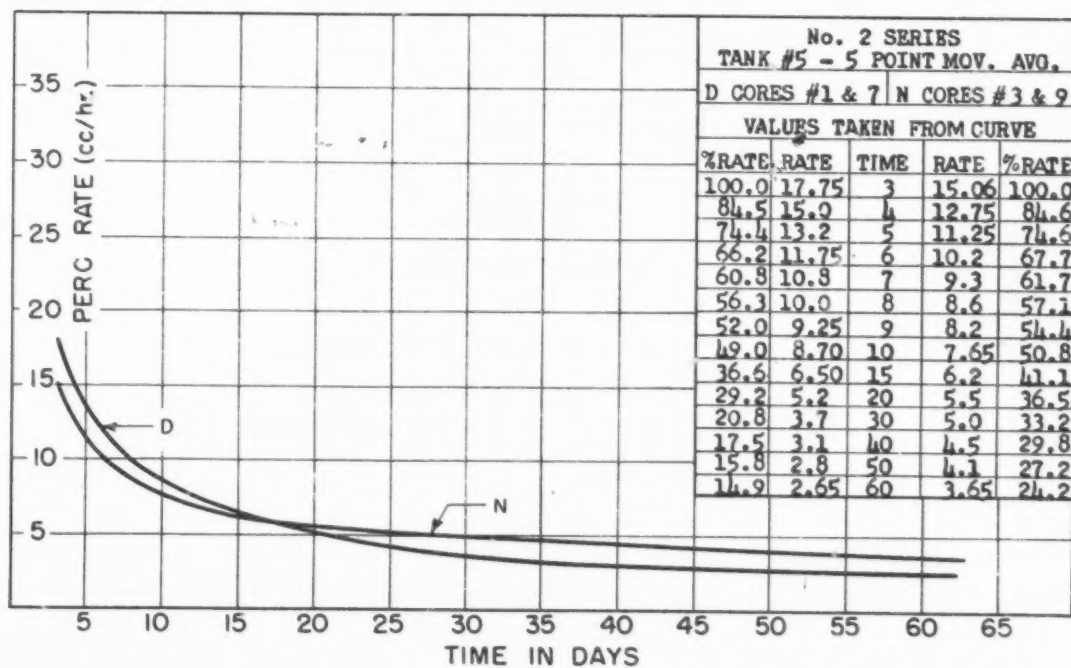
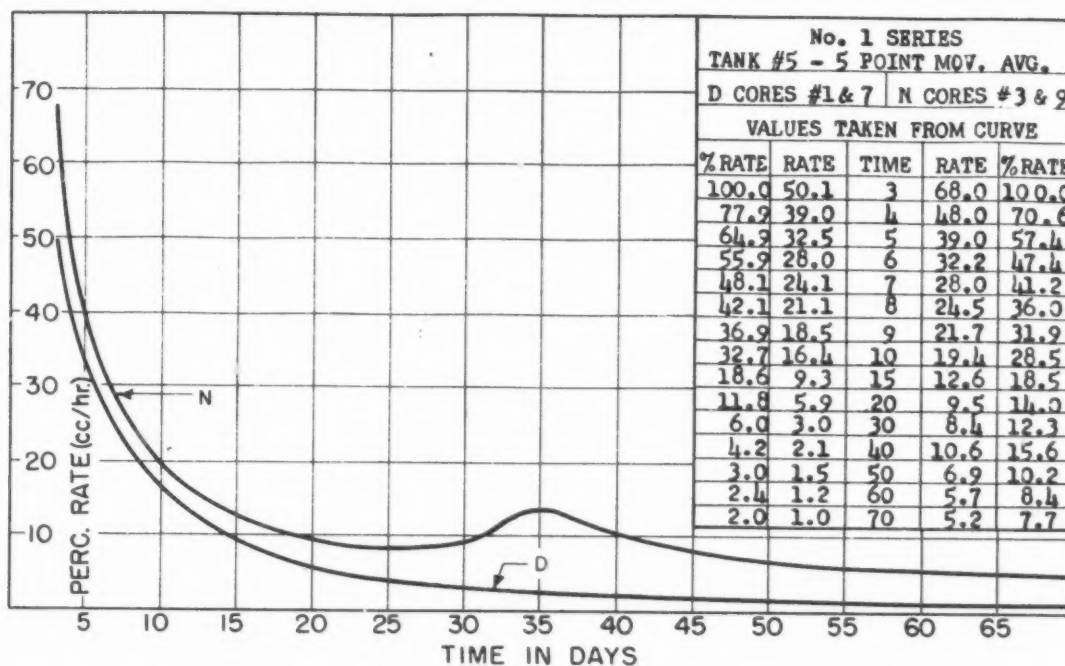
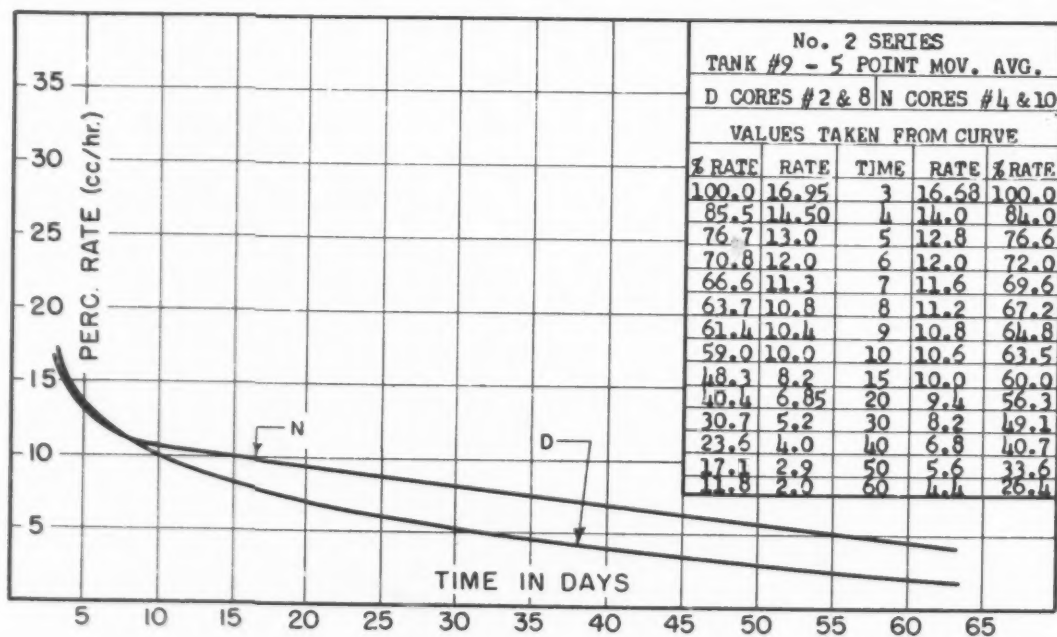
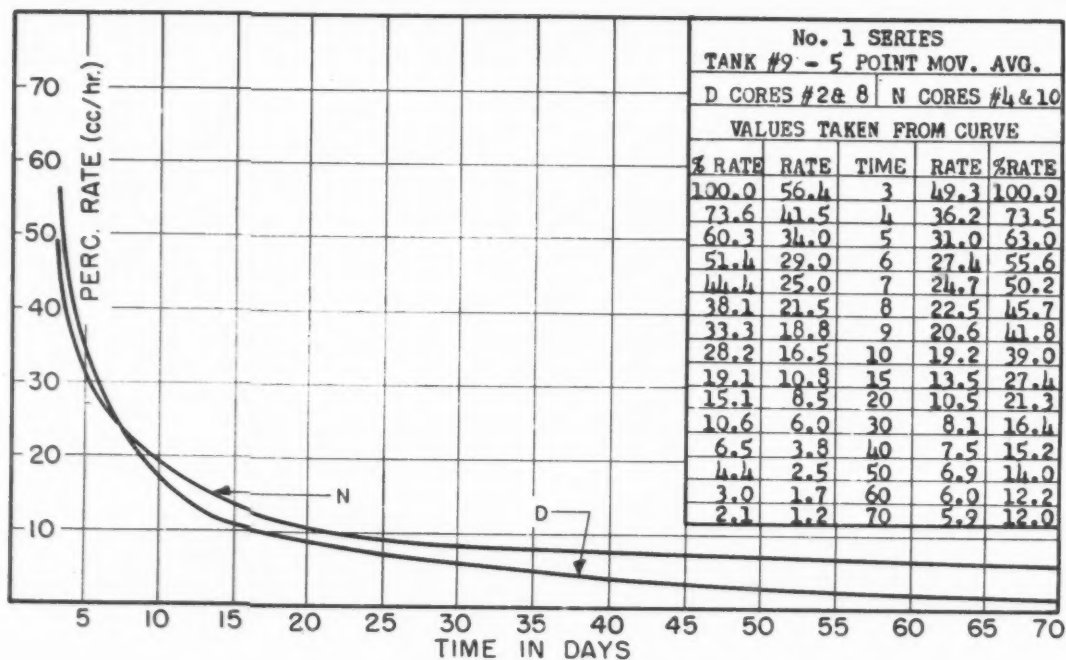


PLATE 31
RATE OF CLOGGING OF PACKED SOIL CORES
AS RELATED TO THE AMOUNT
OF SUSPENDED SOLIDS ADDED



N = NORMAL
D = DISINFECTED

PLATE 32
RATE OF CLOGGING OF PACKED
SOIL CORES AS RELATED TO TIME



N = NORMAL
D = DISINFECTED

PLATE 33
RATE OF CLOGGING OF PACKED
SOIL CORES AS RELATED TO TIME

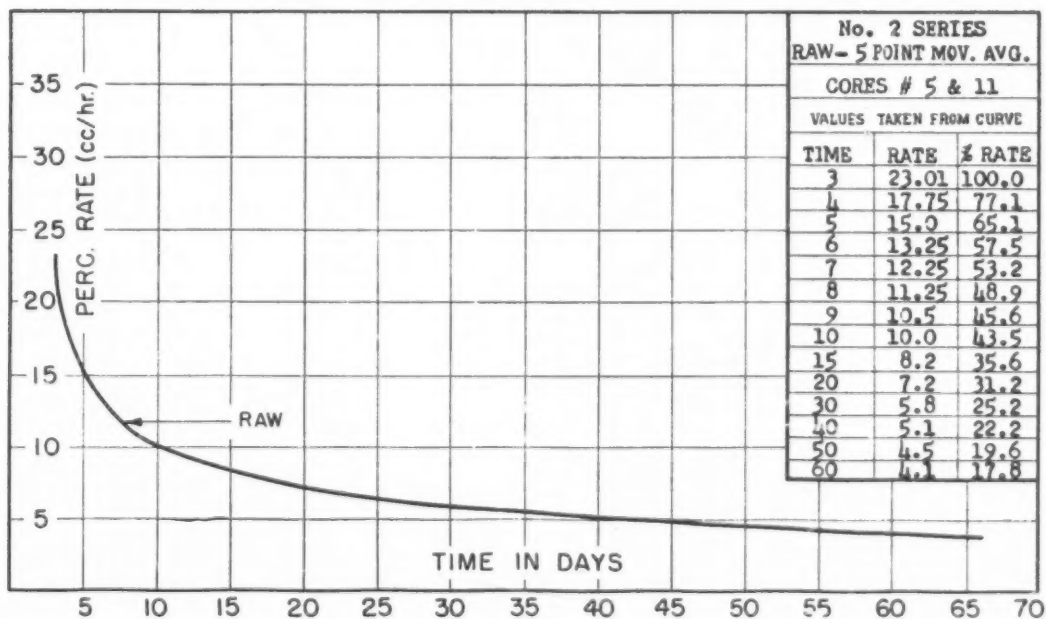
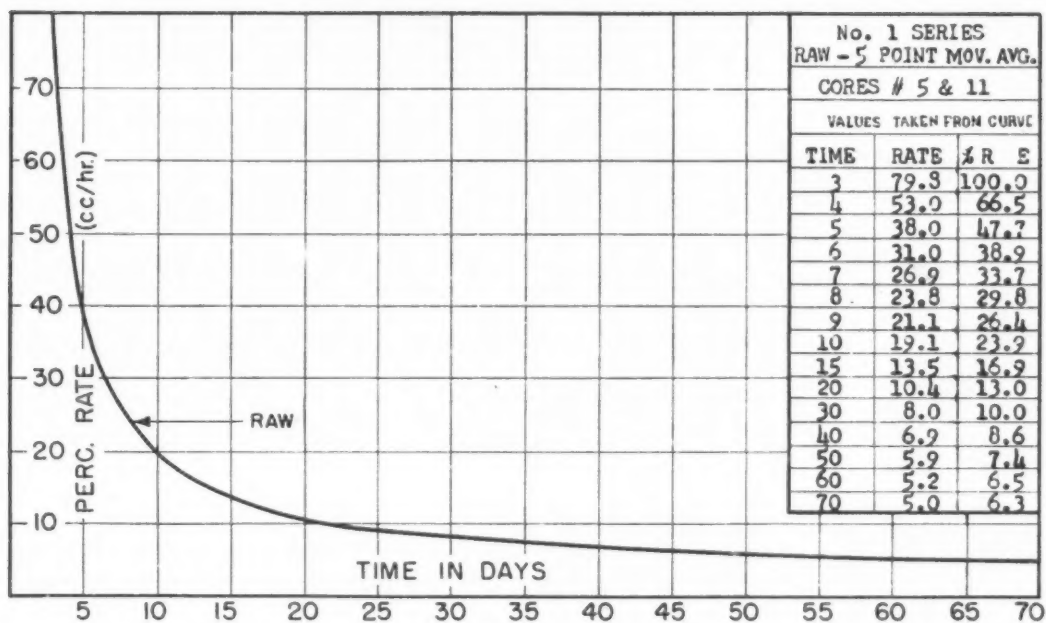


PLATE 34
RATE OF CLOGGING OF PACKED
SOIL CORES AS RELATED TO TIME

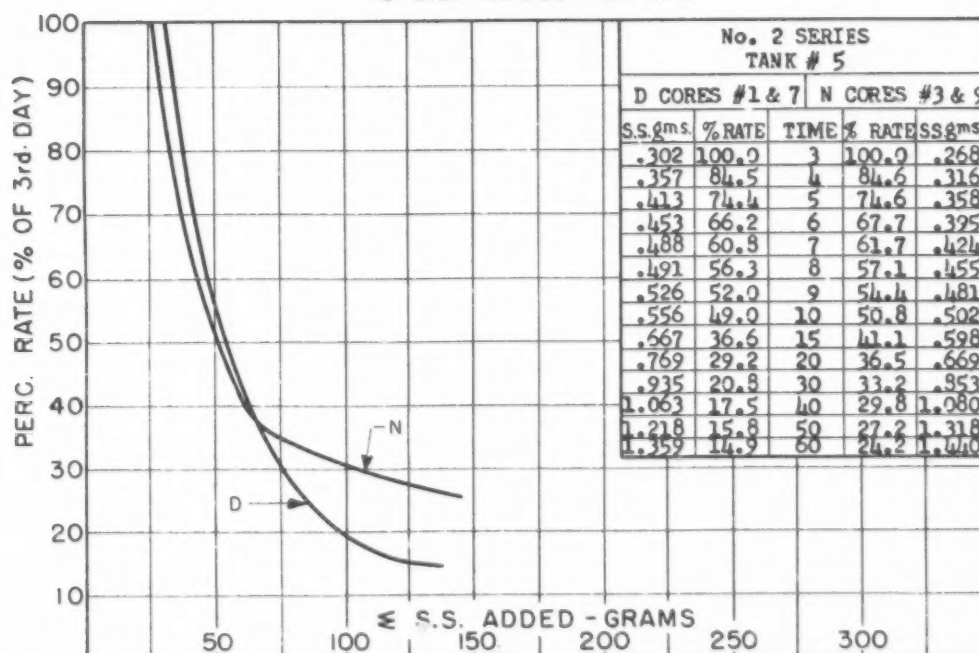
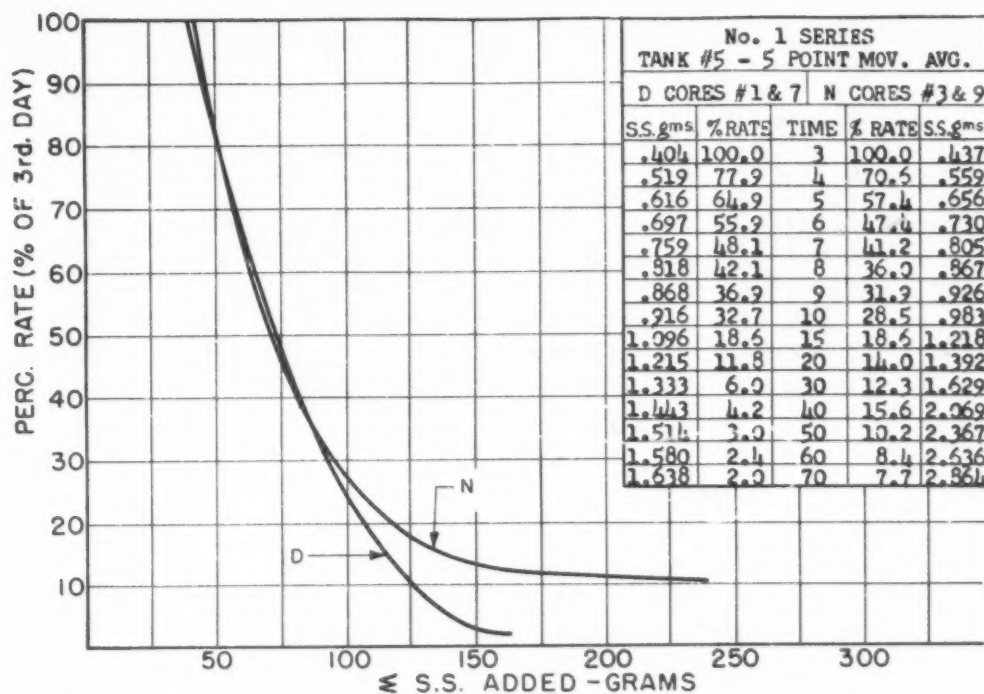


PLATE 35
RATE OF CLOGGING OF PACKED SOIL CORES
AS RELATED TO THE AMOUNT
OF SUSPENDED SOLIDS ADDED

N = NORMAL
D = DISINFECTED

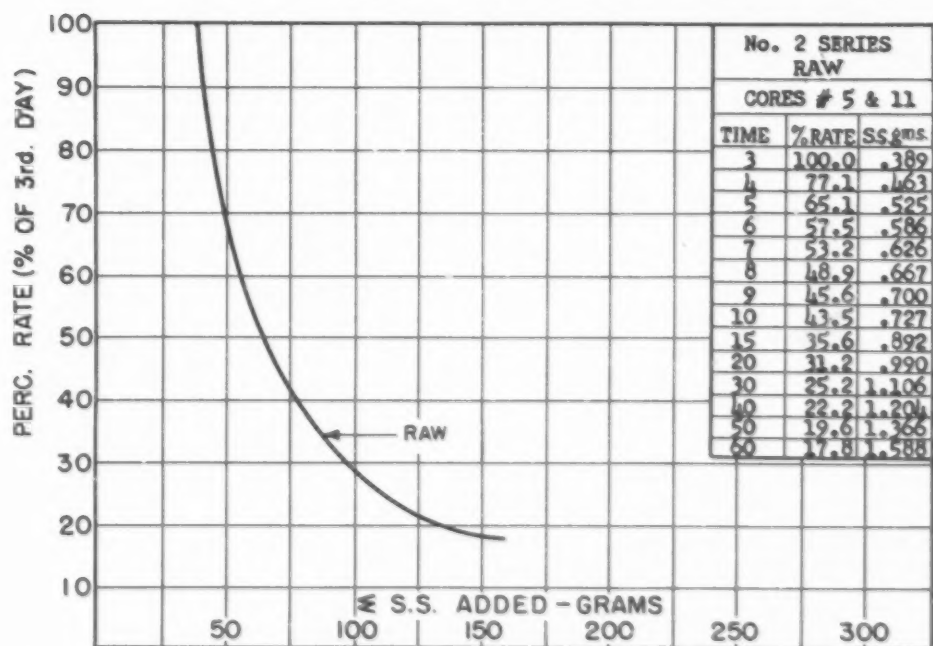
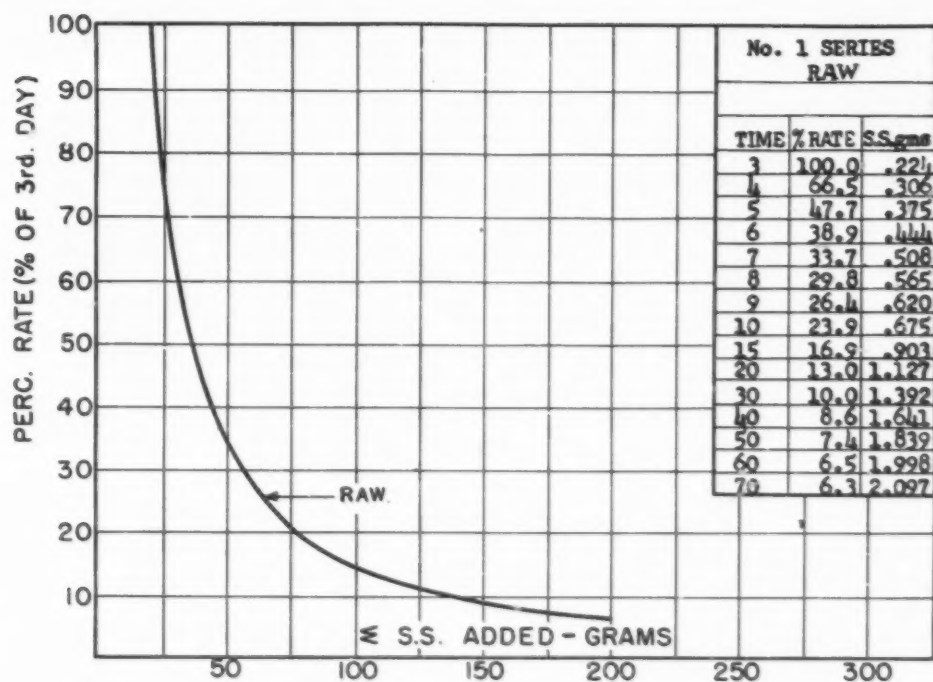


PLATE 36
RATE OF CLOGGING OF PACKED SOIL CORES
AS RELATED TO THE AMOUNT
OF SUSPENDED SOLIDS ADDED

TABLE 32

No. 1 SERIES—TANK No. 9

Disinfected cores Nos. 2 and 8		Time (days)	Normal cores Nos. 4 and 10	
S. S., gm.*	Percent rate		Percent rate	S. S., gm.*
0.235	100.0	3	100.0	0.369
0.495	73.6	4	73.5	0.467
0.583	60.3	5	63.0	0.543
0.654	51.4	6	55.6	0.601
0.705	44.4	7	50.2	0.654
0.757	38.1	8	45.7	0.704
0.803	33.3	9	41.8	0.756
0.848	28.2	10	39.0	0.790
1.020	19.1	15	27.4	1.002
1.215	15.1	20	21.3	1.244
1.598	10.6	30	16.4	1.653
1.862	6.6	40	15.2	2.053
2.086	4.4	50	14.0	2.424
2.193	3.0	60	12.2	2.727
2.300	2.1	70	12.0	3.045

No. 2 SERIES—TANK No. 9

Disinfected cores Nos. 2 and 8		Time (days)	Normal cores Nos. 4 and 10	
S. S., gm.*	Percent rate		Percent rate	S. S., gm.*
0.246	100.0	3	100.0	0.256
0.293	85.5	4	84.0	0.302
0.332	76.7	5	76.6	0.342
0.374	70.8	6	72.0	0.387
0.423	66.6	7	69.6	0.436
0.481	63.7	8	67.2	0.493
0.545	61.4	9	64.8	0.556
0.609	59.0	10	63.5	0.620
0.833	48.3	15	60.0	0.863
1.018	40.4	20	56.3	1.078
1.330	30.7	30	49.1	1.514
1.554	23.6	40	40.7	1.905
1.749	17.1	50	33.6	2.684
1.878	11.8	60	26.4	2.926

* Accumulated suspended solids added.

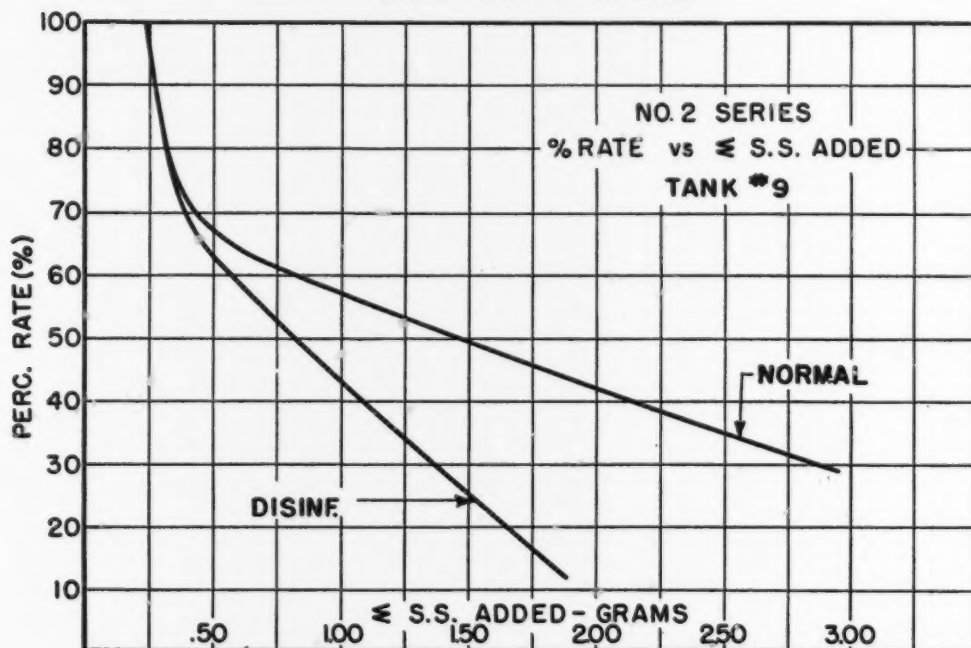
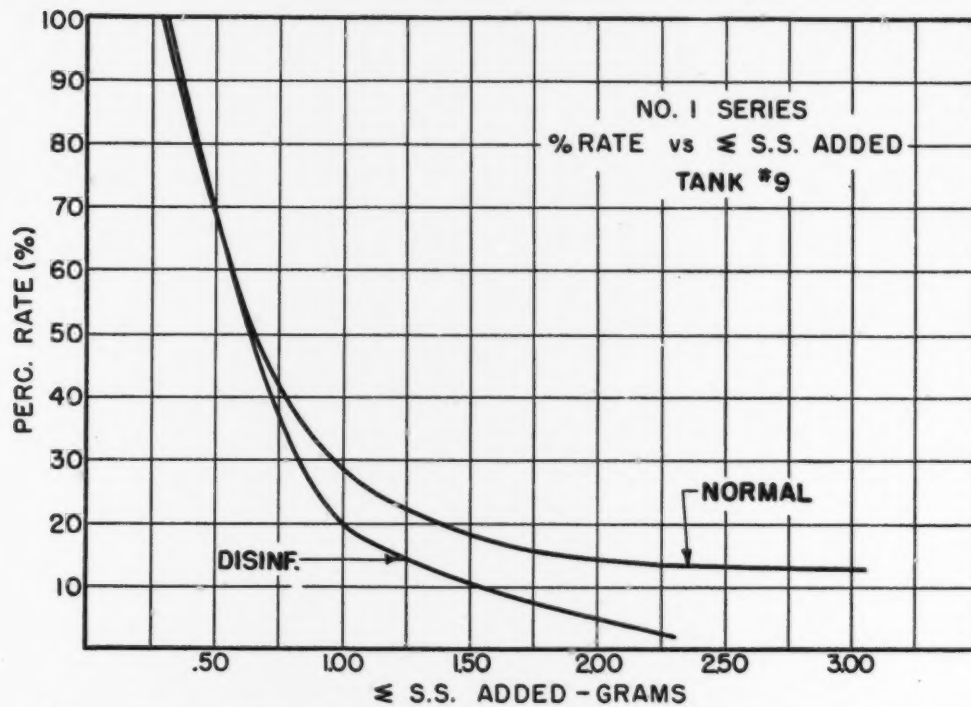


PLATE 37
RATE OF CLOGGING OF PACKED SOIL CORES
AS RELATED TO THE AMOUNT
OF SUSPENDED SOLIDS ADDED